AD-A133 701 PULSE ECHO ULTRASONIC TECHNIQUES FOR UNDERWATER INSPECTION OF STEEL WATERFRONT STRUCTURES(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA 1/2

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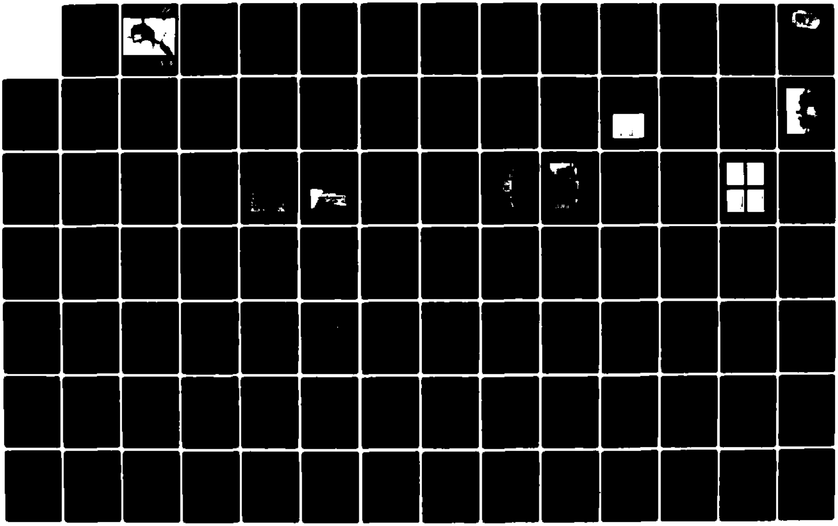

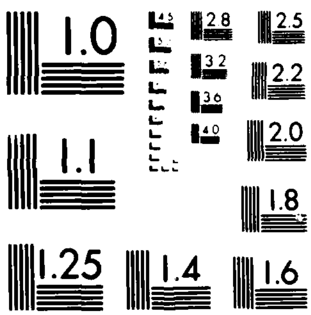

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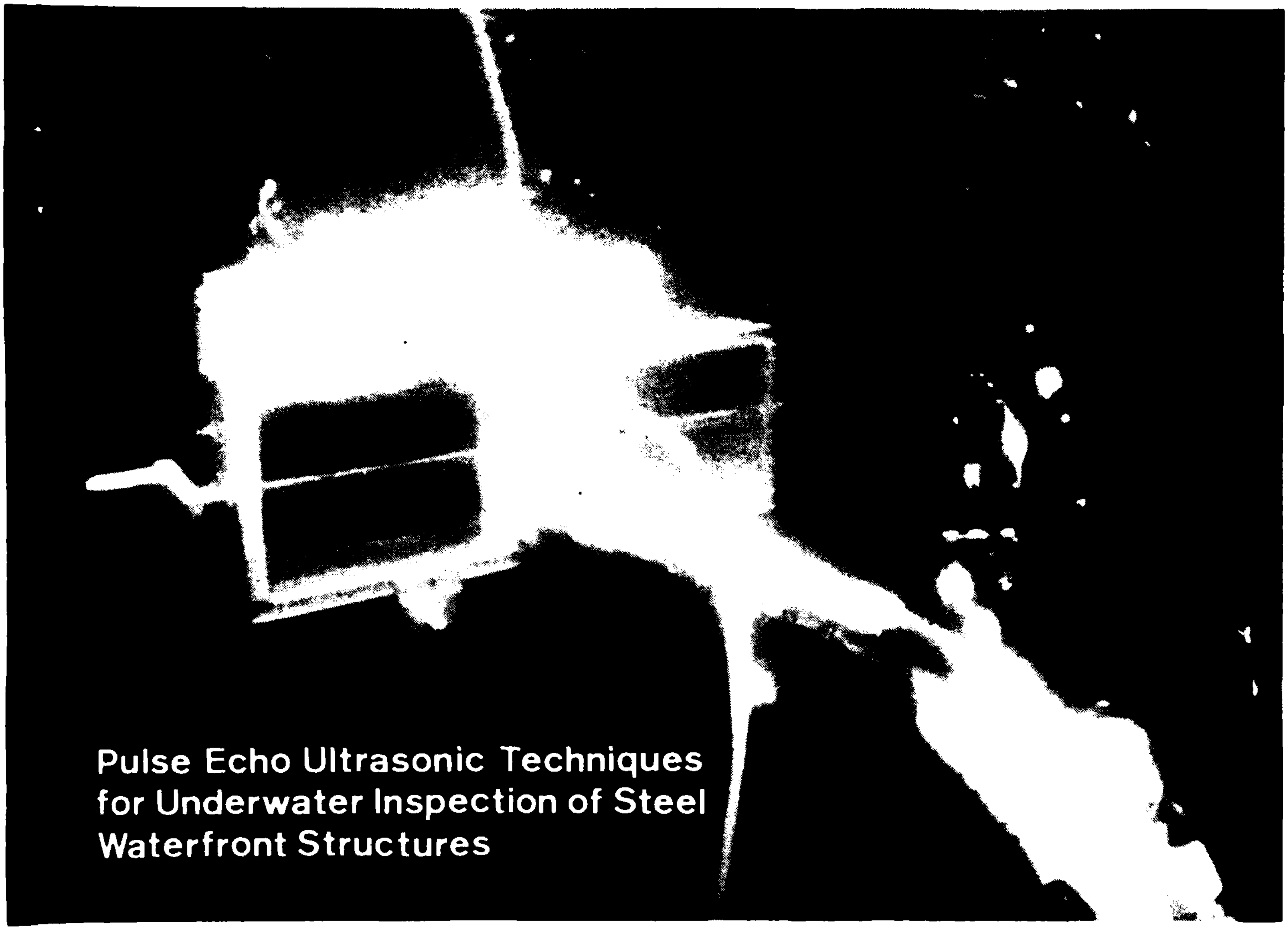


Pulse Echo Ultrasonic Techniques for Underwater Inspection of Steel Waterfront Structures

by R. L. Brackett, L.W. Tucker and R. Erich

June 1983

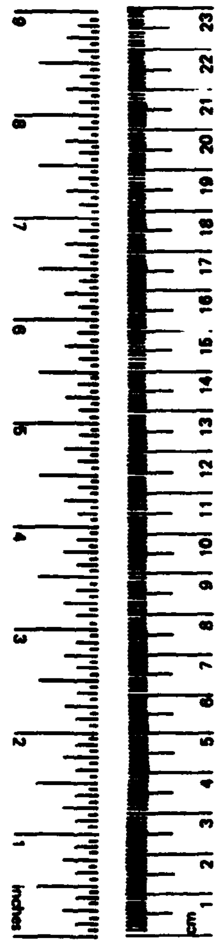
Sponsored by
Naval Facilities Engineering Command

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

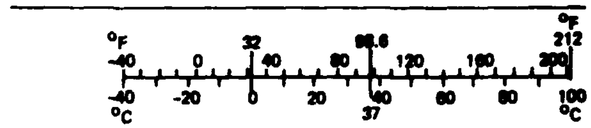
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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This report presents the results of laboratory and field tests to evaluate the capability of commercially available ultrasonic inspection systems to accurately measure the thickness of submerged steel waterfront structures. The objectives of the laboratory tests were to: (1) determine the measurement accuracy using three different methods of acquiring and interpreting the ultrasonic data, (2) identify operator training requirements and optimum information feedback techniques for the diver, and (3) analyze the electrical power transmission

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20. Continued

characteristics of the ultrasonic system and identify any potential safety hazards to the diver. Due to the problems associated with multiple front surface echoes, digital ultrasonic thickness gages should not be used as the only means of inspecting steel structures in areas found to have irregular front surface conditions or where the thickness readings are found to fluctuate rapidly over a small area. Field tests of the ultrasonic scanner and surface milling adapter have confirmed that results comparable to those obtained during laboratory tests are attainable during in-situ inspection of steel pilings; since the ultrasonic scanner and milling adapter technique is not truly nondestructive in nature, however, it should be considered an interim inspection procedure. Investigation of alternative inspection techniques that do not require material removal should be continued. A power system test circuit should be incorporated into any 100-VAC circuit used to power underwater ultrasonic test equipment. As an additional safety precaution, inspection divers should be required to wear neoprene wetsuit gloves and should be instructed not to reach through the air/water interface while holding any grounded electronic equipment in their hands. A series resistor-inductor network connected in parallel with the ultrasonic transducer should be incorporated into all cables greater than 100 feet in length to minimize near-surface noise due to electrical impedance mismatching.

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This report presents the results of laboratory and field tests to evaluate the capability of commercially available ultrasonic inspection systems to accurately measure the thickness of submerged steel waterfront structures. The objectives of the laboratory tests were to: (1) determine the measurement accuracy using three different methods of acquiring and interpreting the ultrasonic data, (2) identify operator training requirements and optimum information feedback techniques for the diver, and (3) analyze the electrical power transmission characteristics of the ultrasonic system and identify any potential safety hazards to the diver. Due to the problems associated with multiple front surface echoes, digital ultrasonic thickness gages should not be used as the only means of inspecting steel structures in areas found to have irregular front surface conditions or where the thickness readings are found to fluctuate rapidly over a small area. Field tests of the ultrasonic scanner and surface milling adapter have confirmed that results comparable to those obtained during laboratory tests are attainable during in-situ inspection of steel pilings; since the ultrasonic scanner and milling adapter technique is not truly nondestructive in nature, however, it should be considered an interim inspection procedure. Investigation of alternative inspection techniques that do not require material removal should be continued. A power system test circuit should be incorporated into any 100-VAC circuit used to power underwater ultrasonic test equipment.

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CONTENTS

INTRODUCTION

Naval shore facilities require periodic maintenance and repair to minimize life cycle costs and maintain a satisfactory level of operational capability. Improvements in the ability of the Naval Shore Establishment to measure readiness with objectivity, consistency, and accuracy are also required. The unexpected failures that have occurred in critical waterfront structures have resulted in direct dollar losses and reduced operational readiness and are also potentially fatal safety hazards. The Office of the Chief of Naval Operations has therefore increased the emphasis on inspection of waterfront operational facilities by requiring that they be included in annual inspection summaries. In response to this requirement, the Naval Civil Engineering Laboratory (NCEL), under the sponsorship of the Naval Facilities Engineering Command (NAVFACENGCOM), has initiated several projects to improve the capabilities of the Navy to conduct underwater inspection and nondestructive testing (NDT) of waterfront structures.

A preliminary analysis of the requirements for underwater nondestructive testing (Ref 1) revealed that the majority of the Navy's waterfront structures are constructed of steel, timber, or concrete. This report also concluded that within the available state-of-the-art pulse echo ultrasonic testing was the most promising technique to provide a near-term improvement in the Navy's underwater inspection capability.

This report presents the results of laboratory and field tests to evaluate the capablity of commercially available ultrasonic inspection systems to accurately measure the thickness of submerged steel waterfront structures. The objectives of the laboratory tests were: (1) to determine the measurement accuracy using three different methods of acquiring and interpreting the ultrasonic data, (2) to identify operator training requirements and optimum information feedback techniques for the diver, and (3) to analyze the electrical power transmission characteristics of the ultrasonic system and identify any potential safety hazards to the diver.

During the early phases of this investigation it became apparent that the irregular front surface condition encountered on submerged corrosion-pitted steel structures was causing erroneous thickness readings to be recorded. These early results caused the emphasis of the testing to shift to investigation of specialized transducer technology and development of techniques to smooth the irregular front surface. The final sections of this report describe the work conducted on corrosion-pitted steel and include the tests and evaluation of specially designed focused transducers and the development and testing of a computerized ultrasonic scanning system adapted with a hydraulic-powered surface mill.

BACKGROUND

The key to improved maintenance and repair management, readiness assessment, and catastrophic failure prevention is improved facility inspection and condition assessment. Inspection, or the gathering of data on the condition of the structural elements of a facility, is at present essentially limited to visual observation. Hidden deterioration cannot be identified until it has progressed to the point where it is revealed by an abnormal surface condition or by structural failure. Specialized inspection equipment and techniques are required to gather data on the condition, both external and internal, of the structural elements of critical facilities in a concise and objective manner. These data must then be analyzed in order to determine the condition of the facility and to establish the detailed maintenance and repair requirements necessary to maintain the facility in its present condition or to improve that condition to required facility capacity.

The purpose of any inspection is to provide the information that is necessary to assess the condition (capacity, safety, and rate of deterioration) of a structure. The usefulness of an inspection depends, therefore, on the suitability of the data obtained to provide the information on those parameters required to make an accurate assessment. A detailed analysis of these data requirements is presented in Reference 2 and summarized in Appendix A.

Two major types of steel structural elements have been identified as being of primary interest for most waterfront inspections: the H-pile and sheet pile sections. Data on the various sizes and configurations of these structural elements are presented in Appendix B. While H-piles are typically used as support elements of a pier of wharf and provide access to all surfaces, sheet piles are primarily used for bulkhead construction and are accessible only from one side.

The predominant cause for the loss of steel cross-sectional area is corrosion. Generally, corrosion is severest in two zones: the splash zone and the region just below the mean low water line. Figure 1 is a typical representation of the relative corrosion rates found in various sections of a steel pile. As holes develop and enlarge in steel sheet pile walls, the backfill may erode away, eventually leading to a failure that penetrates the ground surface or pavement. The rate of corrosion depends in part on the conditions in the harbor. High dissolved oxygen content, low pH levels, and stray electrical currents all tend to accelerate corrosion. Water particle velocity also affects the rate of corrosion, as shown in Figure 2.

Another type of corrosion, generating black rust, is caused by certain bacteria found in seawater near the mud-submerged zone interface. The bacteria are capable of reducing sulfates to sulfides under anaerobic conditions. The sulfides are highly corrosive and combine with iron to form a black iron sulfide product. The result of the corrosion process in many instances is a steel structure with very irregular surface characteristics. This corrosion pitting can range from isolated pinhole size pits to ones large enough to engulf the better part of a diver's thumb. In many cases the pitting is found to be generalized in coverage and ranges from 0.04 and 0.1 inch in depth and 1/8 to 1/2 inch in diameter.

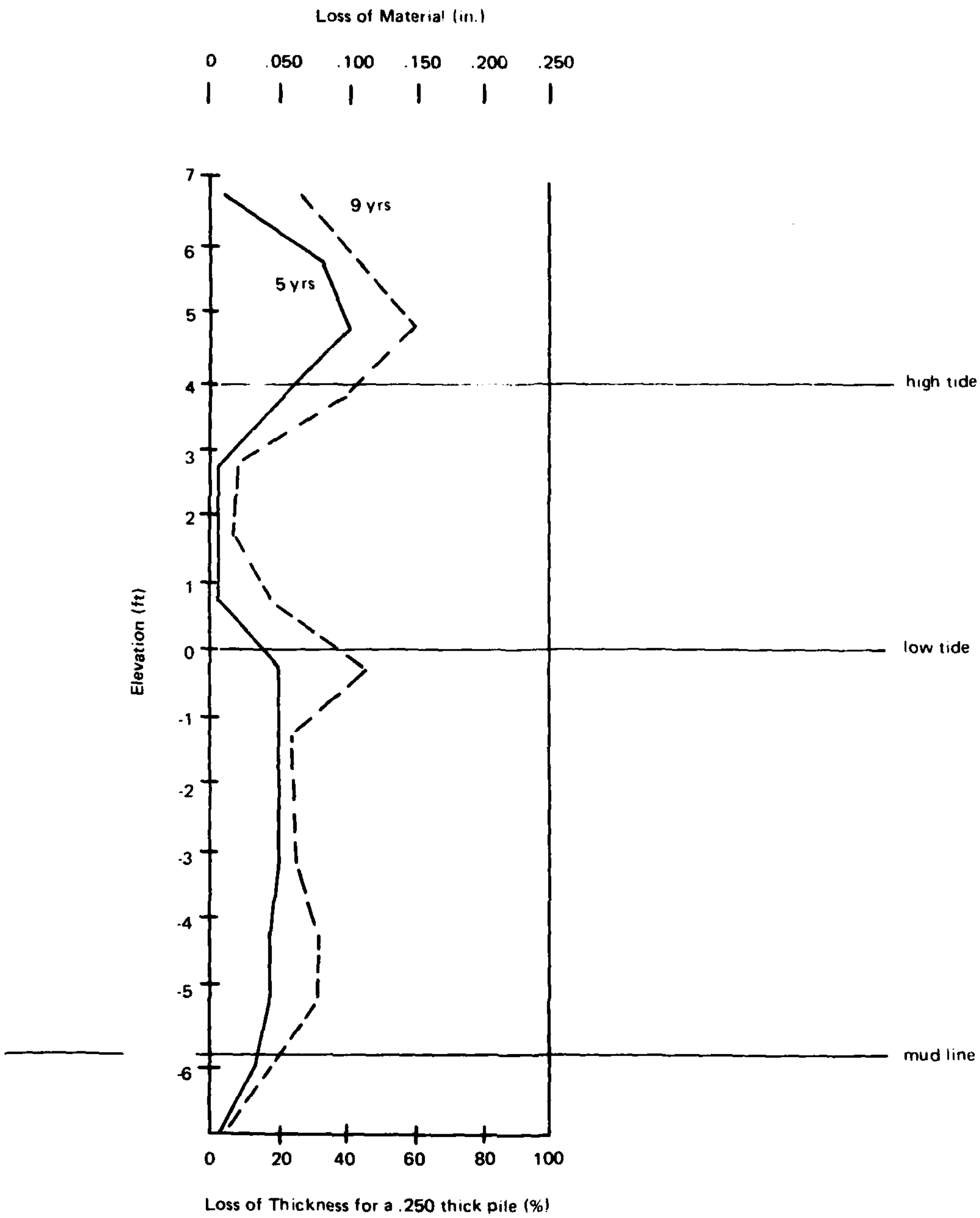


Figure 1. Relative corrosion rate for various elevations of steel piles.

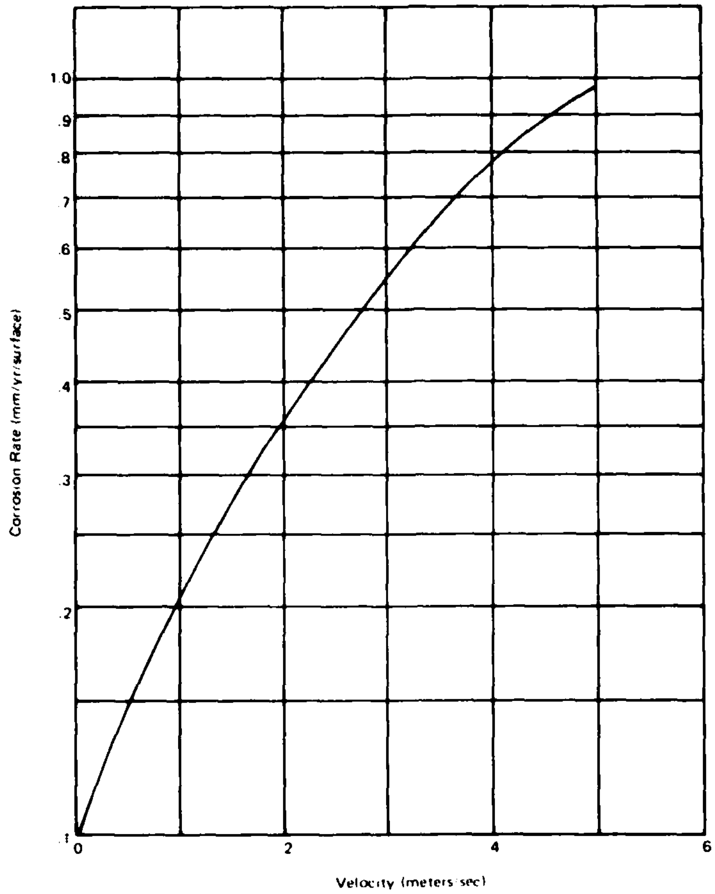


Figure 2. Effect of water particle velocity on rate of corrosion.

ULTRASONIC TESTING TECHNIQUES

Applications

Ultrasonic testing provides a versatile, nondestructive inspection technique for numerous applications, including thickness measurement, flaw detection, imaging of opaque objects, and material property determination. The application of primary interest for inspection of waterfront structures is the determination of remaining metal thickness of a corroded steel structure. In this application, a pulse of high frequency sound is transmitted into the test specimen; the time interval between the transmitted pulse and the return echo reflected from the back surface is measured and correlated with the material thickness. If the velocity of sound in the test material is known, the material thickness can be calculated from the relationship

$$x = v \cdot t/2$$

where

x = thickness

v = sound velocity

t = time of flight of sound pulse

In most instances, however, the ultrasonic test unit is configured such that the time delay can be scaled to provide a direct distance (thickness) measurement as the output of the instrument.

Basic Components

Figure 3 is a block diagram of the major system assemblies of an ultrasonic test unit. The heart of the system is the timer or rate generator. This component is the source of all timing signals to other parts of the system. The trigger signal from the timer simultaneously produces a high voltage output from the pulser and initiates the sweep on the cathode ray tube (CRT) screen. The pulser produces the high voltage signal that is transmitted to the transducer, where it is converted to mechanical (ultrasonic vibration) energy, and simultaneously to the receiver circuit, where it is processed for display on the CRT. If the test unit is equipped with a digital readout, the initial pulse also triggers the time/voltage conversion assembly.

When the return echo reaches the transducer, it is converted to an electrical signal and amplified by the receiver. This signal then stops and holds the time/voltage analog signal; it is simultaneously displayed on the CRT screen.

The preceding discussion highlights only the most basic components of the system for the reader with little or no background in ultrasonic nondestructive testing. A more detailed discussion of this subject and general ultrasonic theory can be obtained from Reference 3 or any one of numerous texts on ultrasonic technology.

Equipment Description

Based on information obtained on the use of pulse echo ultrasonic testing in the North Sea and United States (reported in References 1 and 4), a decision was made to purchase a conventional ultrasonic flaw detector for initial laboratory testing.

A survey of commercially available, portable ultrasonic inspection systems resulted in the selection of a Sonic Instruments, Inc. Mark IV flaw detector with a Model 220 digital thickness adapter (Figure 4). The digital thickness adapter provides an external analog voltage proportional to the material thickness. This analog signal was transmitted to a Hewlett-Packard digital voltmeter (model HP-3437A), which converted the thickness analog to a binary code and transferred it to a Tektronix 4052 desktop computer over an IEEE 488 interface bus. This system, shown schematically in Figure 5, was used to acquire, analyze, and store on magnetic tape all thickness data generated during laboratory testing.

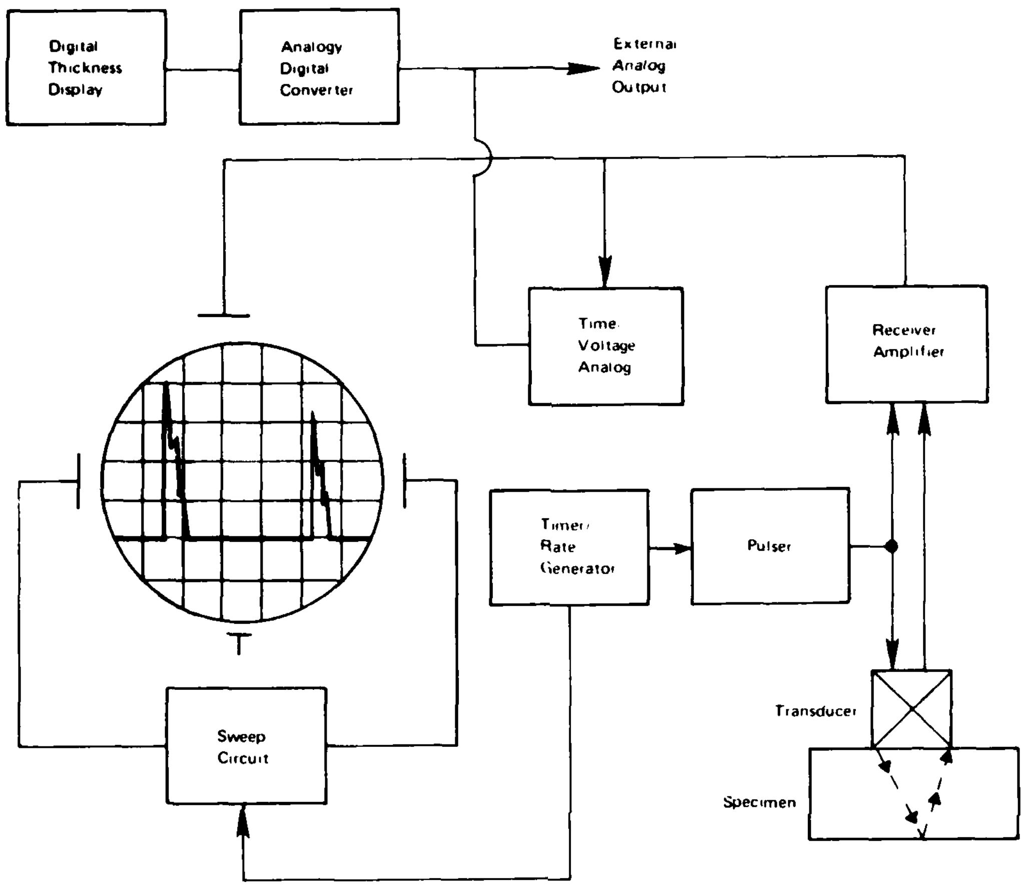


Figure 3. Basic subsystem assemblies of an ultrasonic test unit.

LABORATORY TESTING

Equipment Calibration and Measurement Accuracy Tests

The first series of laboratory tests was set up to determine the accuracy of the thickness readings obtained by personnel with various levels of ultrasonic training when (1) interpreting the visual CRT display on the Mark IV flaw detector, (2) reading the digital thickness display on the 220 adapter, or (3) acquiring the thickness data directly with the computer.

Based on the work reported by Mittleman (Ref 5 and 6), the computer programs for calibration of the ultrasonic transducer and thickness data acquisition were developed using a second-order polynomial regresssion analysis. This allowed the computer-generated calibration curve to account for nonlinear thickness to transit time correlations generally found to occur with focused and dual-element ultrasonic transducers.

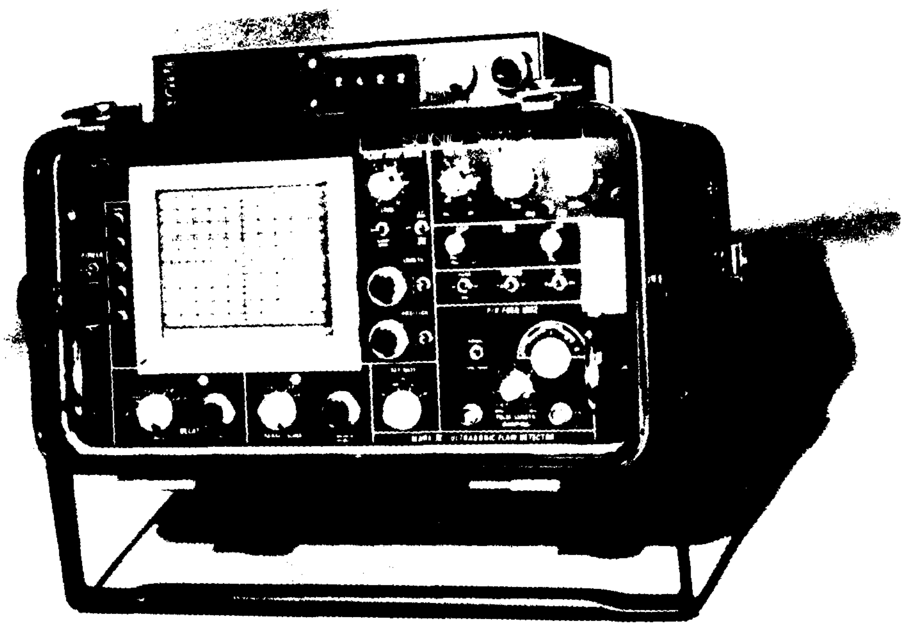


Figure 4. Ultrasonic flaw detector.

An analysis conducted to determine the effect of using high-order polynomial regressions of the calibration data revealed that although the closeness of fit of the data to the resulting calibration curve improved with higher order equations, extrapolation of the calibration curve outside the boundaries of the calibration thickness values was impossible. The effect of using higher order regression analysis is shown in Figure 6, which represents the calibration curves resulting from second-, fifth-, and seventh-order polynomial regression analyses.

The first series of tests was conducted to determine the accuracy of measuring metal thickness ultrasonically as a function of both the level of training of the ultrasonic technician and the method of acquiring and interpreting the ultrasonic data. Eleven gage blocks with random thicknesses ranging from approximately 1/10 inch to 1 inch were fabricated for use as test specimens. After a brief review of the test objectives and instrument calibration procedures, eight personnel with ultrasonic training levels ranging from no formal training to American Society of Nondestructive Testing (ASNT) Level II certification were required to calibrate the Mark IV flaw detector and digital thickness adapter. They were then directed to measure the thickness of the 11 blocks, first by using the visual display on the CRT, then by obtaining a digital reading from the 220 adapter, and finally by taking a reading using the computerized data acquisition system. A total of three readings for each block and each data acquisition technique were taken during a single test.

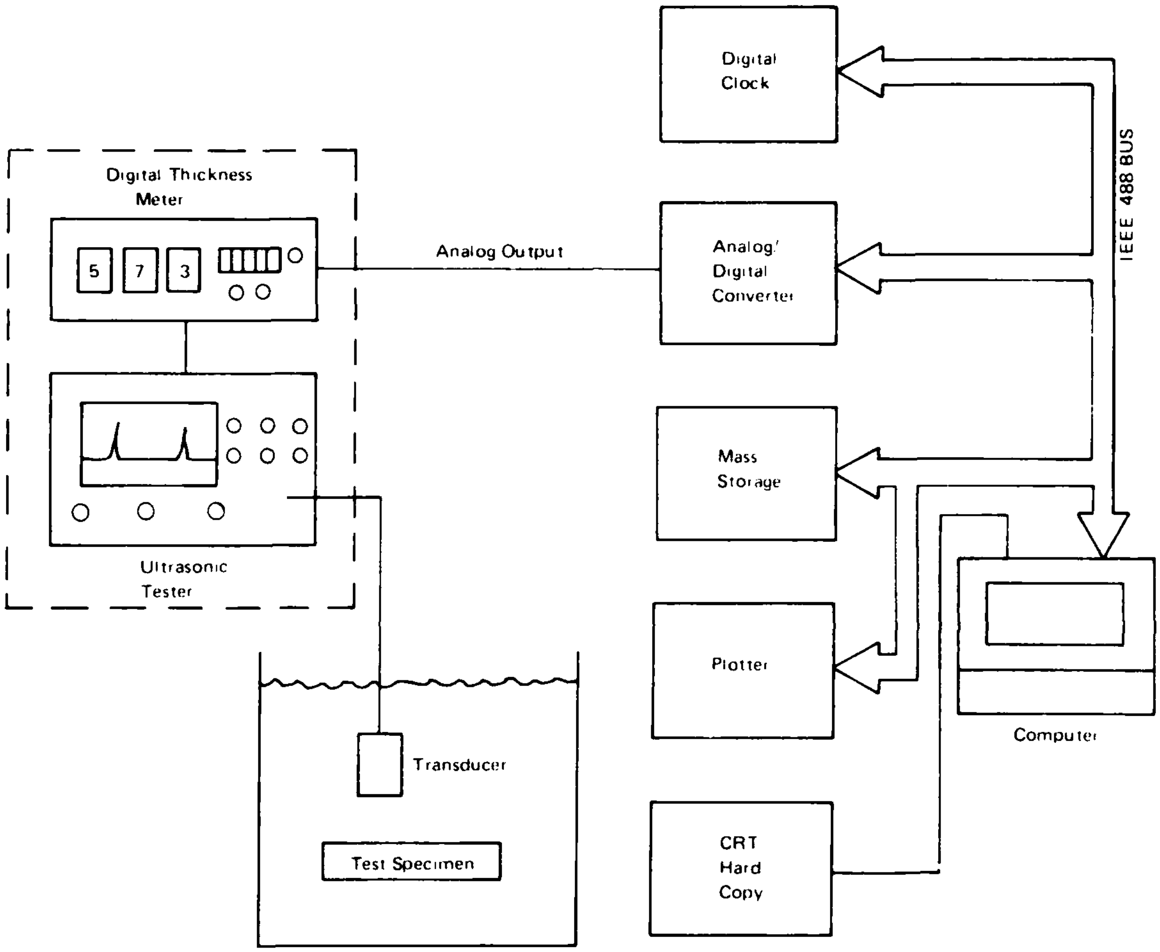


Figure 5. Schematic of ultrasonic thickness test system.

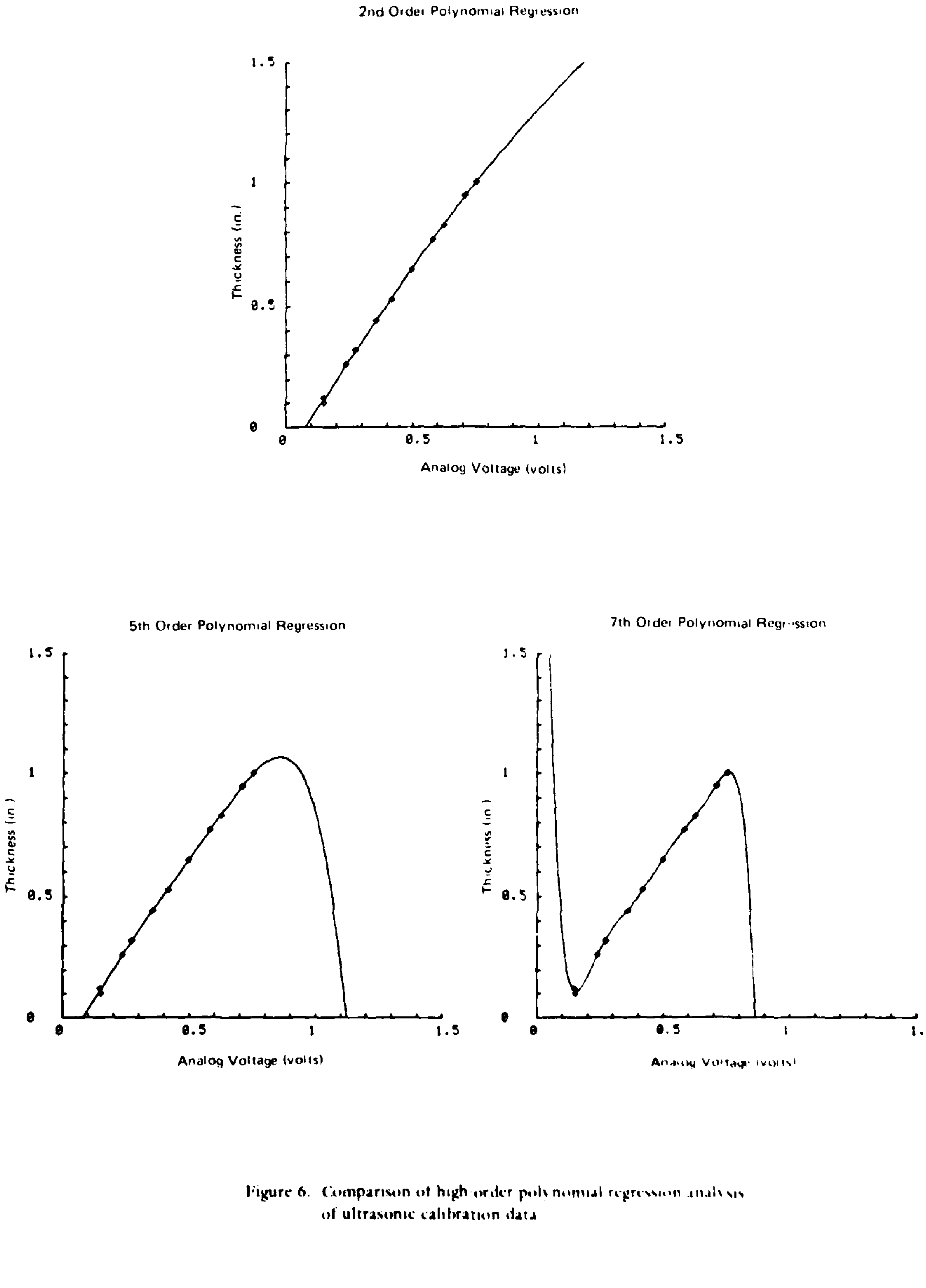


Figure 6. Comparison of high-order polynomial regression analysis of ultrasonic calibration data

The computer was then used to calculate the difference between the measured and "actual" thickness of the blocks (obtained from precision micrometer measurements); the results were displayed as a function of measurement technique and level of operator training. Figure 7 is typical of the results obtained from these measurement error analysis tests.

Analysis of 28 series of tests revealed that, with as little as 30 minutes training on the use of the flaw detector, each of the eight test subjects obtained comparable measurement accuracies with each of the three data acquisition techniques. Slight improvements in measurement accuracy were noted from test to test as the subjects became more familiar with the operation of the equipment. However, no correlation was found between the initial level of training and the ability of the operator to properly calibrate the instrument or to obtain accurate measurements.

However, a distinct difference was found in the accuracy of the thickness measurements depending upon the data acquisiton technique employed. Table 1 lists the mean error and other relevant statistical parameters for each of the three data acquisition techniques.

Table 1. Thickness Measurement Accuracy for Three Data Acquisition Techniques

Parameter	Data Acquisition Technique		
	CRT	Digital	Computer
Mean error (in.)	0.00604	0.00421	0.00085
S*andard deviation	0.00740	0.00390	0.00097
Minimum error (in.)	0.00003	0.00000	0.00005
Maximum error (in.)	0.03906	0.01391	0.00395

The significance of the variation in measurement errors can be best appreciated when it is related to the inspection data and analysis requirements presented in Reference 2. From the discussion on inspection strategy in that report, the relationship between the required number of measurements and instrument accuracy to obtain a desired level of confidence in the condition assessment can be expressed by:

$$n = \left[\frac{2\,z\,\sigma}{c \cdot m - c_e} \right]^2$$

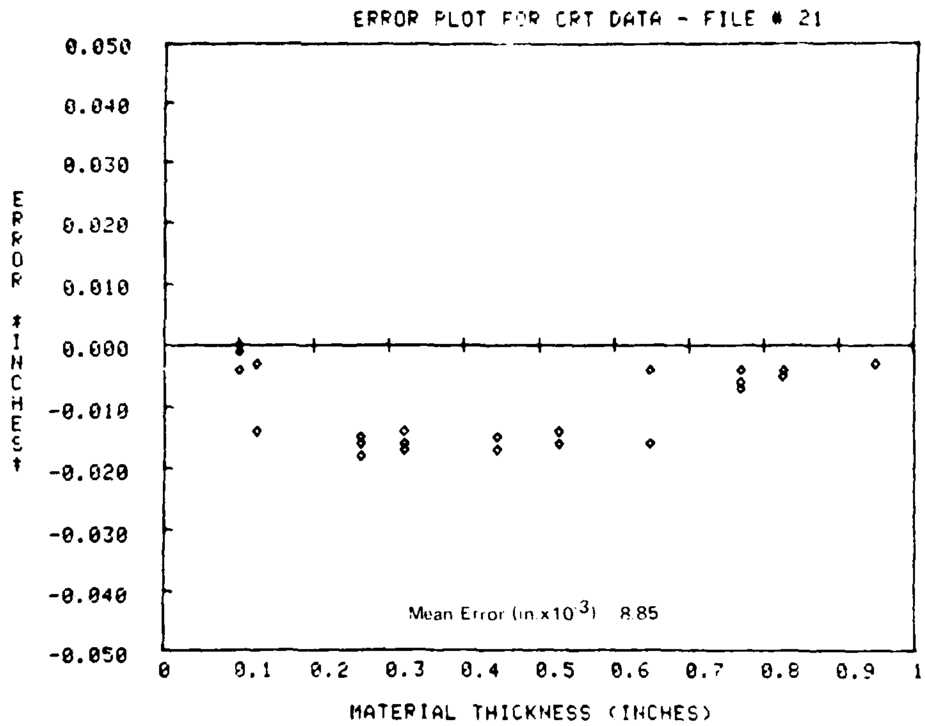


Figure 7a.

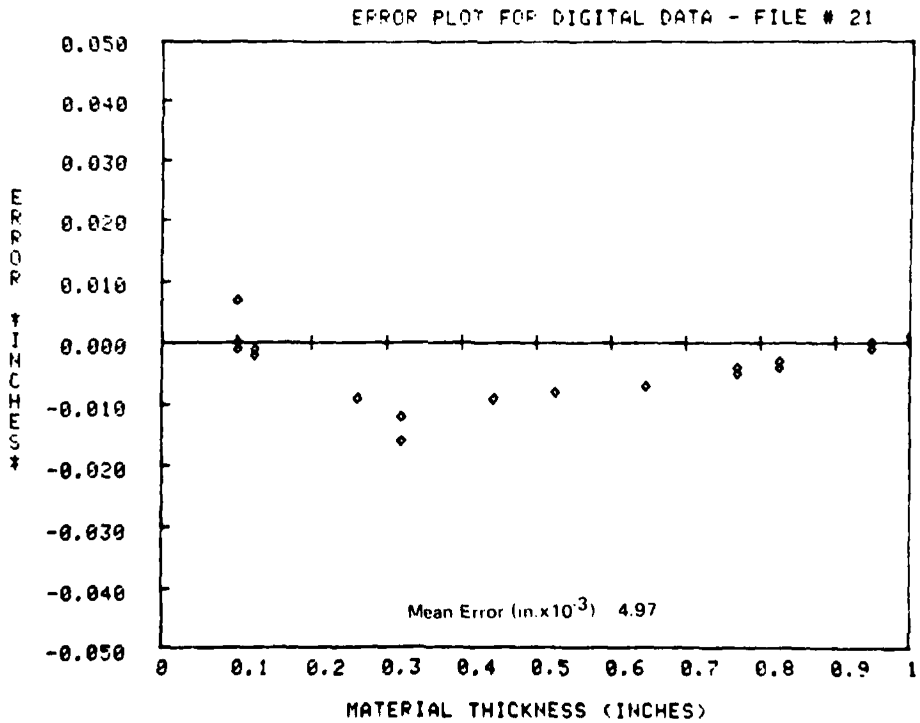


Figure 7b.

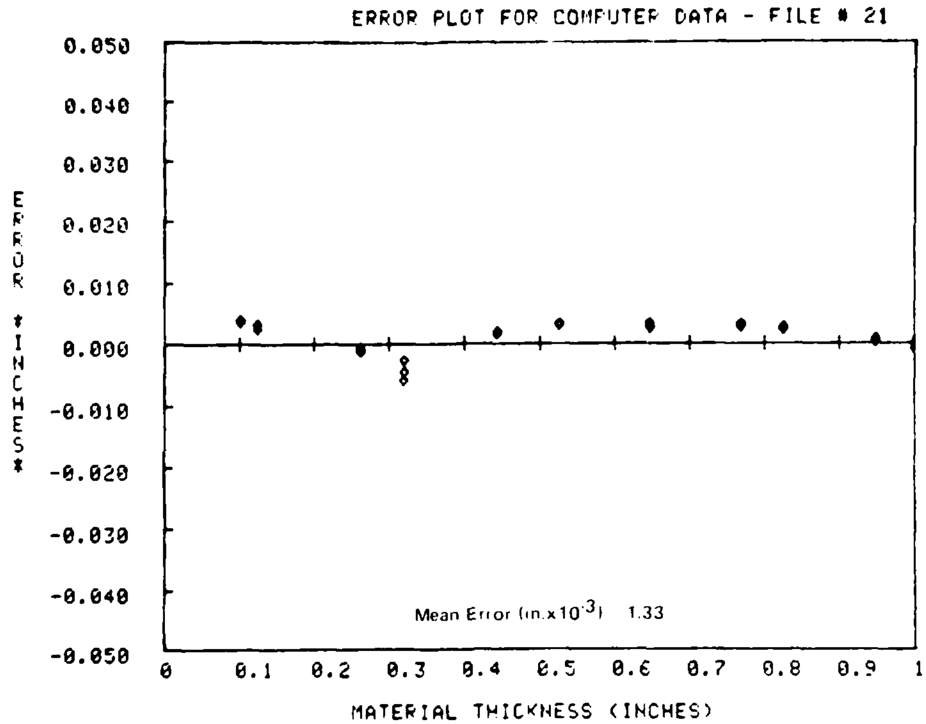


Figure 7c.

Figure 7. Ultrasonic metal thickness measurement error analysis.

where

n = required number of readings

c = acceptable error in the inspection data

c_e = calibration error of the instrument

σ = standard deviation of the thickness of the structural element

m = mean thickness of the structural element

z = normal deviate corresponding to the desired confidence interval

Using the 4% accuracy requirement for H-pile thickness measurement discussed in Appendix A and a standard deviation of 0.0118 obtained from NCEL tests on a typical corrosion-pitted H-pile specimen, Figure 8 shows the relationship between the required number of readings per pile and the average thickness for the three data acquisition techniques to obtain 90% confidence that the measured average thickness is within 4% of the true average thickness. For example, when measuring a pile with an average thickness of 0.5 inch, the measurement requirement varies from four readings for computer acquisition to eight readings for visual interpretation of the CRT-displayed signal. If, however, the average

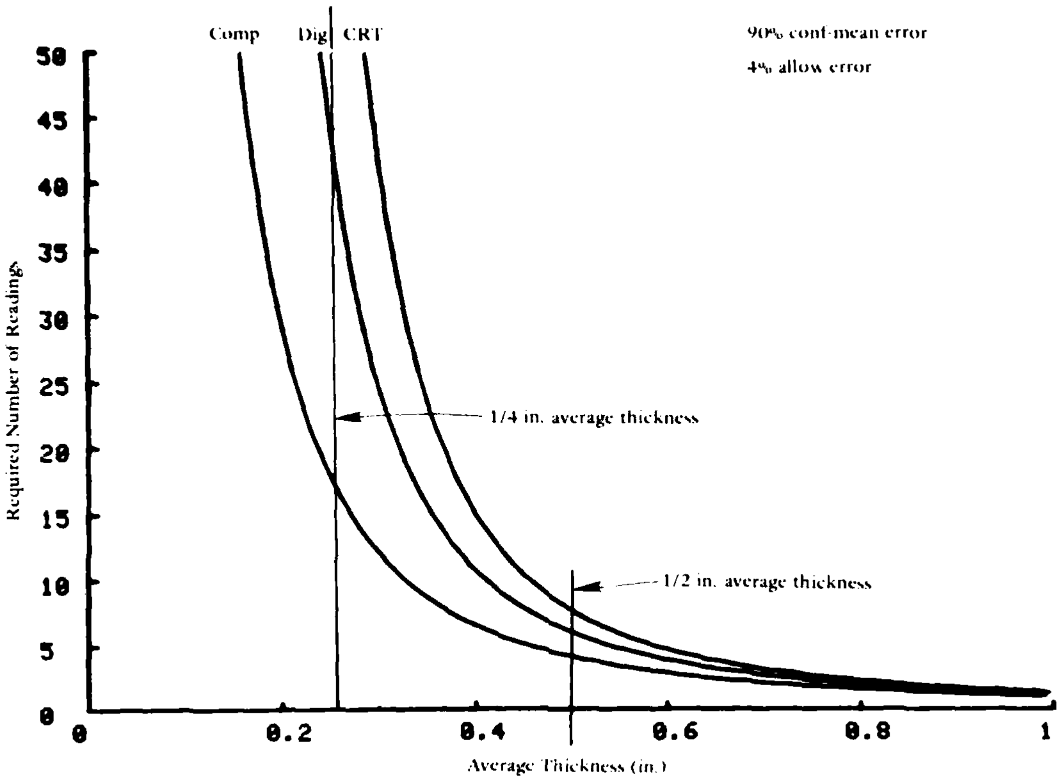


Figure 8. Data sample requirements.

thickness has decreased to 0.25 inch the difference in measurement requirements becomes much more dramatic. Using computer acquisition and interpretation, 18 readings are required, while digital readout requires 41 readings and CRT interpretation requires so many readings as to become economically impractical.

Electrical Safety Testing Program

The electrical trigger pulse used to excite the piezoelectric transducer has a peak voltage of 600 volts with a maximum repetition rate of 3,000 pulses/sec. Since the diver could be exposed to this pulse voltage if the cable were to be cut or the transducer disconnected, tests were conducted to determine whether this posed a potential safety hazard.

Analysis of the data obtained from these tests showed that the 600-volt pulse output to the transducer is the only voltage on the cable handled by the diver. The triangular pulse has a magnitude of 12 amperes and a width of approximately 1×10^{-6} second. At the maximum pulse rate of 3,000 pulses/sec, a time-averaged current of 3.6 mA could be delivered. This is just above the perception level and is considered to not represent a danger to the diver.

Examination of the electrical schematic revealed that the 110-VAC input to the Mark IV flaw detector is used only to charge the onboard battery. Power for operation of all other subsystems is provided by this 24-VDC source. Failure of any internal component that resulted in a direct short to the transducer cable would allow no more than the 24-VDC potential to be transmitted to the diver. This is below the danger level for DC voltages and is not considered a safety hazard to the divers.

During initial testing both in the NCEL Shallow Water Ocean Simulation Facility and at Key West, Florida, the difference in potential between the transducer case (connected to the utility system ground) and the seawater ground was sufficient to produce an uncomfortable shock to the diver if the diver's hand was raised out of the water while holding the transducer.

The susceptibility of a diver to electrical shock is greatly increased by the reduction in contact resistance caused by seawater absorption into the skin. On dry land, hand-to-hand path resistance can range from 10,000 to 100,000 ohms. For a diver coming out of the water, this resistance ranges from 500 to 1,000 ohms. If the diver makes contact with a 5- to 10-VAC source or a 30- to 60-VDC source, an electrical shock with currents exceeding the "let go" level could be experienced. The let go level is defined as the maximum current at which voluntary muscle control can be exercised to let go of the electrical source. The let go levels are approximately 9 mA for AC current and 60 mA for DC current.

Besides the obvious problems associated with damaged transmission wires, voltages of sufficient magnitude to deliver a shock to the diver can be present without direct contact with a live wire. The most common situation is for the diver to touch a device that is grounded to the shore-based utility system but is not at the same potential as the seawater. Contact is most dangerous when the diver reaches through the air/water interface while holding electric-powered equipment and the current path is from the hand through the arm and body to seawater.

To eliminate future occurrences of this problem, a power system test circuit has been developed that allows measurement of ground system potential differences prior to commencing diving operations. In addition, the system will shunt the utility system ground to the seawater potential if necessary. Appendix C contains a schematic of this circuit and a procedure for conducting the tests and interpreting the results of the power system test.

PRELIMINARY UNDERWATER TESTING

Initial underwater tests were conducted in the NCEL Shallow Water Ocean Simulation Facility. The objectives of these tests were to familiarize the divers and topside technicians with the operation of the ultrasonic equipment in a controlled environment and to determine the most efficient communication system to assist the diver in the proper

positioning of the transducer. The communication techniques investigated included: (1) verbal instructions from the topside ultrasonic technician; (2) an audio tone, the frequency of which was proportional to the amplitude of the back surface echo; and (3) visual display of the signal as it appeared on the CRT of the flaw detector.

Shortly after the initiation of this test series, it became apparent that a much more serious problem than identifying the best information feedback system was being experienced. A large number of the thickness readings being recorded were outside the range of known minimum-to-maximum thickness obtained for the corrosion-pitted test specimen from previous caliper measurements. Because of the relatively high accuracy of thickness measurements obtained during the previous calibration tests conducted with smooth-surfaced test specimens, the erroneous reading problem was attributed to the irregular front surface condition encountered with the corrosion-pitted specimens.

To confirm this hypothesis, five test blocks were prepared from bar stock having a nominal thickness of 1/2 inch. Simulated pits ranging in depth from 0.025 inch to 0.158 inch were machined in each block using a 1/4-inch-diam ball mill. Tests were conducted first with the transducer located over the pit on the front surface and then with the transducer located over the pit on the smooth back surface. Table 2 presents the results of these tests.

Table 2. Comparison of Ultrasonic and Micrometer Measurements of Specimens with Simulated Pits

Block No.	Micrometer Measurements (in.)			Ultrasonic Measurements (in.)		
	Maximum Thickness	Pit Depth	Minimum Thickness	Pit on Front Surface	Pit on Back surface	
					Minimum	Maximum
1	0.493	0.025	0.468	0.125	0.472	0.492
2	0.489	0.048	0.441	0.198	0.456	0.495
3	0.497	0.082	0.415	0.328	0.415	0.495
4	0.494	0.104	0.390	0.420	0.399	0.496
5	0.493	0.158	0.335	0.664	0.335	0.491

Comparison of the ultrasonic "thickness" readings with the micrometer measurements for each block revealed that with the transducer positioned over the pit on the front surface, the digital ultrasonic reading was not representative of any dimension of the test samples. Analysis of the signal appearing on the CRT on the flaw detector showed a decrease in the strength of the front surface echo and an irregularly shaped "back surface" echo when compared to signals obtained from smooth specimens. This phenomenon suggests that the ultrasonic signal is being reflected from the various levels of the front surface resulting in multiple echos, which can be misinterpreted as material thicknesses.

Since the speed of sound in water is approximately one-fourth the speed of sound in steel, the "thickness" readings obtained should be about four times the pit depth if the erroneous readings are a result of multiple front surface echos. Table 3 shows that there is excellent correlation between the ultrasonic measurements and a dimension that is four times the pit depth.

Table 3. Comparison of Ultrasonic Reading and Pit Water Path

Block No.	Pit Depth (in.)	Pit Depth x 4 (in.)	Ultrasonic Reading (in.)
1	0.025	0.100	0.125
2	0.048	0.192	0.198
3	0.082	0.328	0.328
4	0.104	0.416	0.420
5	0.158	0.632	0.644

Tests conducted with the transducer located on the smooth back surface produced ultrasonic measurements of both minimum and maximum thickness. The results of this series of tests are summarized in Figure 9, which shows typical CRT displays and digital ultrasonic readings for the three different surface conditions examined. In Figure 9a, a specimen with smooth front and back surfaces produces sharp and distinct echoes from both surfaces, which results in accurate digital readings. In Figure 9b, a specimen with back surface pitting produces a strong front surface echo, but a slight decrease in the back surface echo is noted due to the scattering of the sound energy. The digital reading again gives an accurate indication of the decreased metal thickness caused by the rear surface pit. Figure 9c is typical of the results obtained from specimens with front surface pitting. The initial front surface echo (a) shows a decrease in amplitude since only part of the energy is being reflected from this level. The echo reflected from the bottom of the pit is much more irregular than the back surface echoes shown above. Since the instrument is calibrated for the speed of sound in steel, the digital "thickness" reading produced by these multiple front surface echoes is approximately four times the pit depth and has no correlation with actual material thickness.

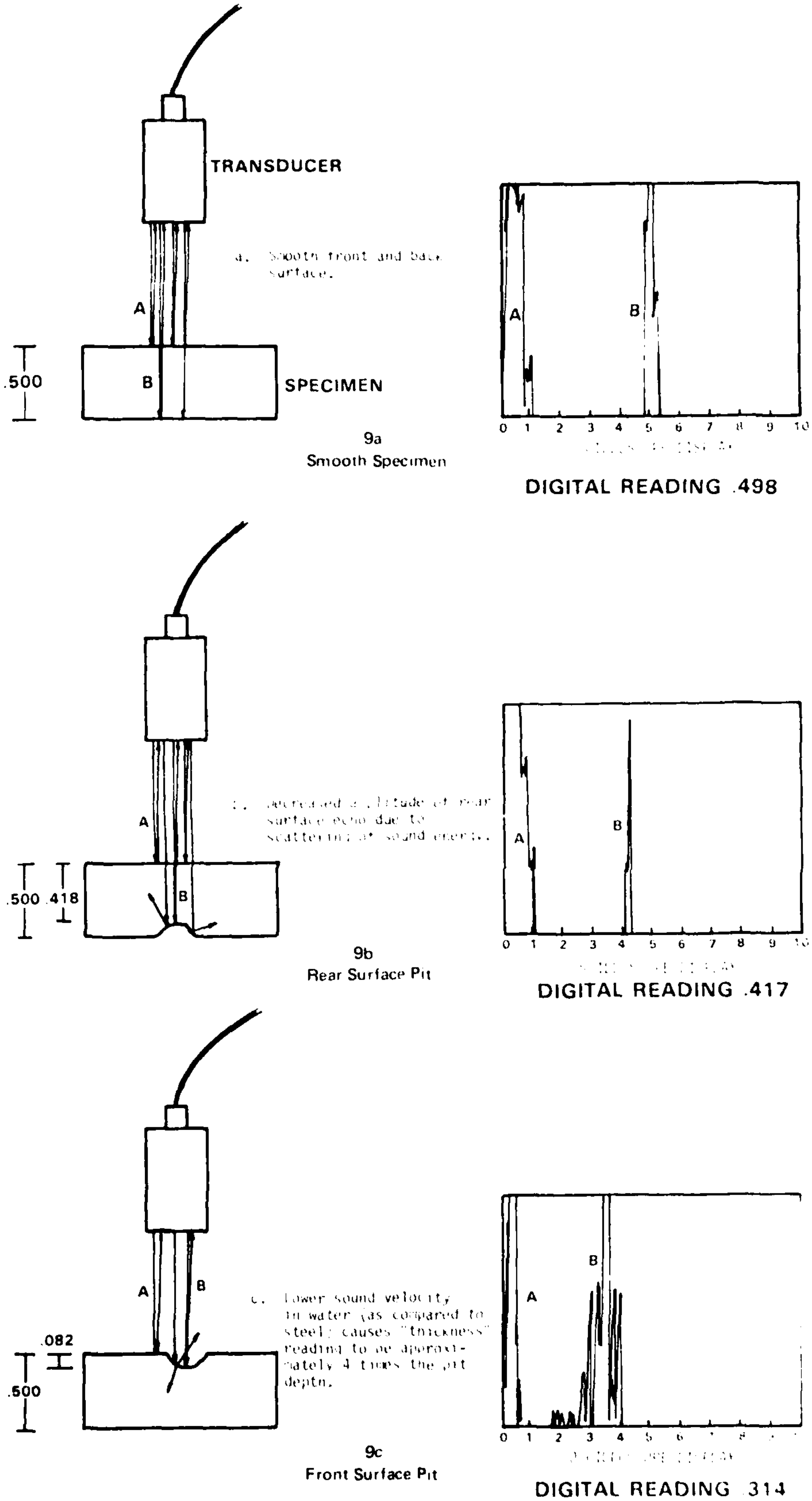


Figure 9. Comparison of CRT and digital ultrasonic readings for 3 different surface conditions.

In an attempt to solve the multiple front surface reflection problem, a feasibility study and laboratory tests were conducted with numerous specialized array systems. Although some limited success was obtained on tests of the simulated pit specimens with specially designed, conically focused transducers developed at Southwest Research Institute (Ref 7), none of these transducers resulted in a practical solution to the problem when attempting to examine actual corrosion-pitted samples (Figure 10) where the pits were interconnected and had a wide variety of pit depths.

Field tests conducted on H-piles in Port Hueneme Harbor, California, and sheet pile in Key West, Florida, confirmed that this phenomenon was not due to some peculiarity with the specimens used during the laboratory and tank tests. On tests of the H-pile sections in the region between mean low water and 5 feet below mean low water, numerous areas with heavy corrosion pitting were encountered. In these areas, over 40% of the ultrasonic thickness readings were greater than the original thickness of the material and over 80% were greater than the maximum thickness obtained from caliper measurements. In Key West, an entirely different situation was encountered. A heavy coral encrustation had protected much of the sheet pile from deterioration; reasonable ultrasonic readings were obtained from the smooth surfaces presented when the protective coral growth was removed. On the portion of the pier subjected to heavy tidal currents, this coral coating apparently had not been as effective, and numerous regions with pits "large enough for the divers to insert their thumbs" were encountered. In this area of the structure (covering approximately one-third of the inspection sites), no back surface echoes or plausible ultrasonic readings were obtained.

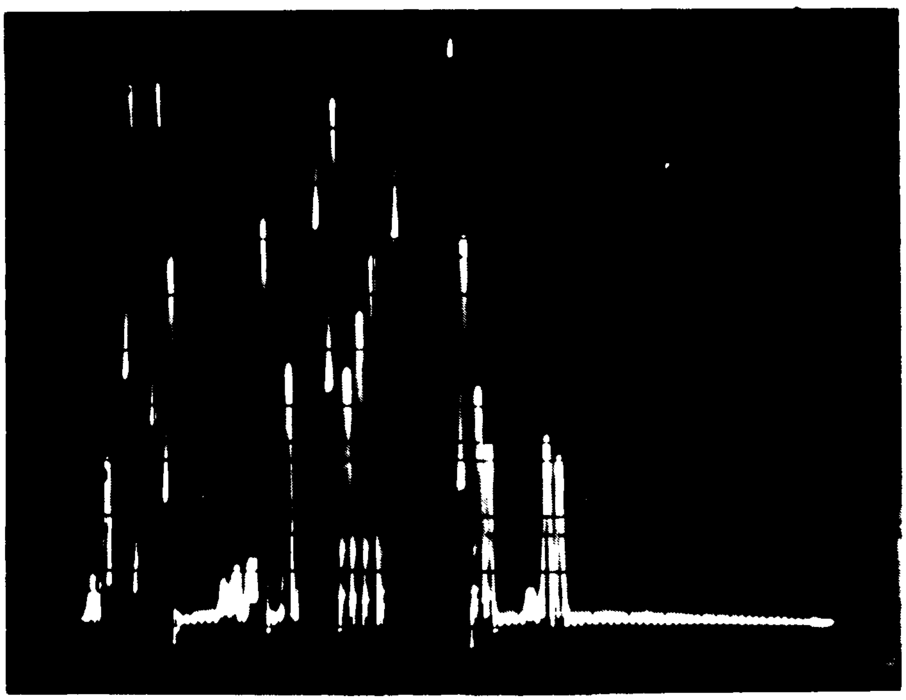


Figure 10. CRT display of ultrasonic signal produced during examination of a pitted specimen using a conically focused transducer.

ULTRASONIC SCANNER AND SURFACE MILL DEVELOPMENT

Scanner Development

Based on the partial success obtained with the conically focused transducers on simulated pits with spherical geometries, it was felt that an ultrasonic scanner system that related thickness readings to a precise spot on the surface of the test specimen might allow discrimination between true thickness and erroneous multiple front surface readings. The reasoning behind this approach was twofold. First, if actual thickness measurements could be obtained, they would tend to overlap on a position-indexed scan, while multiple front surface readings would tend to vary with position depending upon the direction of approach of the transducer. Second, since the average cross section over the entire width of the structural element was of interest, there was concern that the average calculated from a nonposition-correlated scan might be unduly biased by a few smooth spots on the surface if there was no way to fix their positions.

The scanning mechanism developed for these tests consists of a bridge that holds both the ultrasonic transducer and a high-precision, 10-turn potentiometer to locate the relative position of the transducer with respect to the scanner framework. Figure 11 shows the cross-sectional layout of the scanner bridge. The bridge is moved along the support framework by means of a screw feed mechanism. The total travel distance is 15 inches, which is sufficient to accommodate the largest H-pile cross section. The scanner frame is attached to the structural element with four magnets rated at 300 pounds pull each. The original design called for much smaller magnets, but subsequent tests revealed that on pitted surfaces only 15% to 20% of the rated pull strength could be developed, thus necessitating the use of the larger magnets. Figure 12 shows the overall configuration of the scanner.

For the experiments, the excitation voltage for the position potentiometer was supplied from a 15-VDC output from the Mark IV flaw detector. The signal voltage was then fed into an analog-to-digital converter and transmitted to the computer over the IEEE-488 interface bus. Simultaneous triggering of both analog-to-digital converters connected to the ultrasonic transducer and the position potentiometer assured correlation between the thickness and position readings.

Figure 13 is one of the early scans obtained with this equipment. This scan was taken on a four-step calibration bar measuring 8 inches in length with steps from 0.200 inch to 0.500 inch in 0.100-inch increments. Examination of this scan shows that very accurate reconstruction of a cross-sectional shape is possible using this technique.

Next, scanner tests were conducted on a test specimen that had been surface milled to remove the corrosion-pitted irregularities from one face. Scans plotted with the transducer positioned on the smooth side produced recognizable and accurate plots of the back surface pitting (see Figure 14). Calculations of the average thickness from the data resulted in an estimate that was within 0.1% of the actual average plate thickness obtained from measuring the volume and area of the plate.

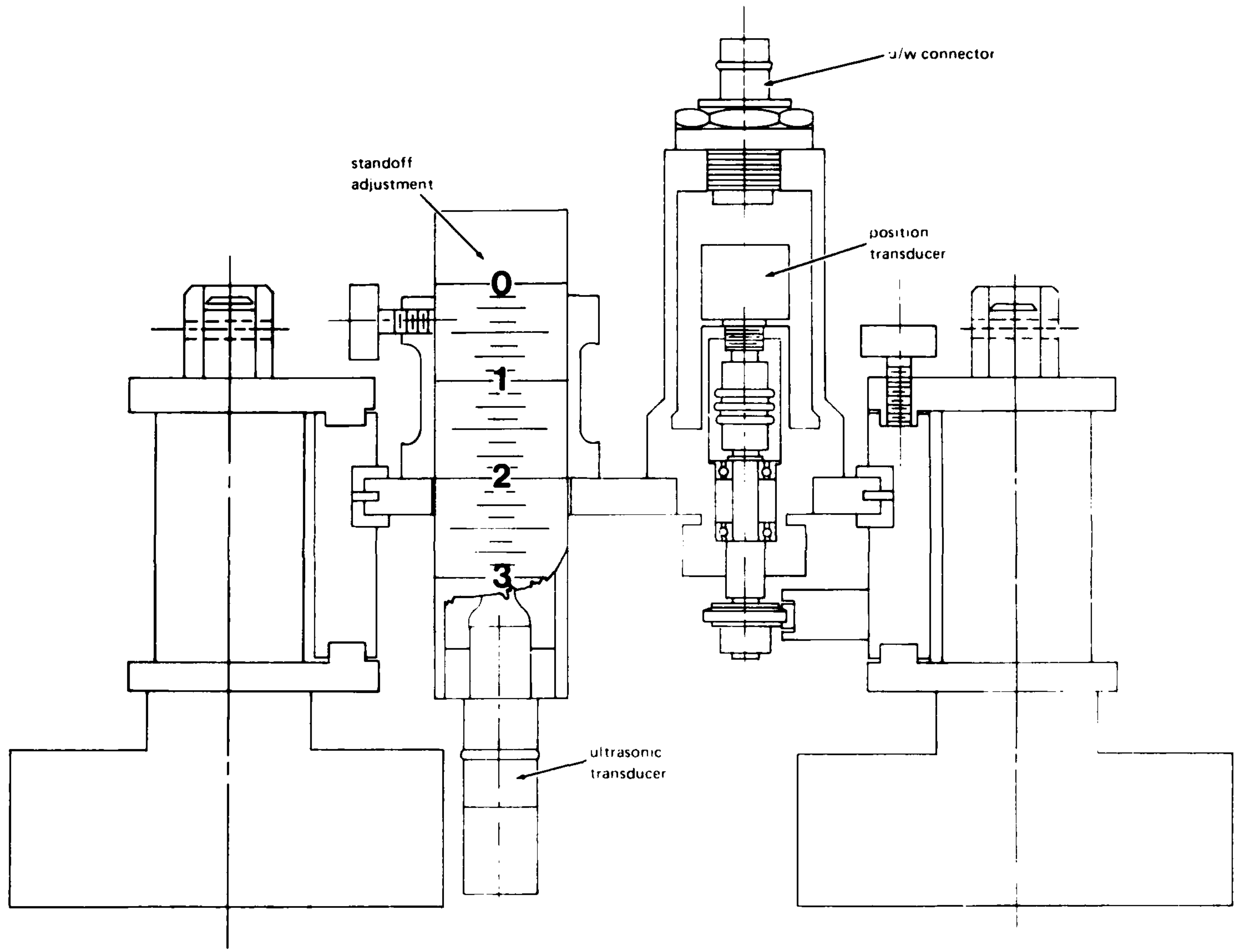


Figure 11. Cross section of ultrasonic scanner bridge.

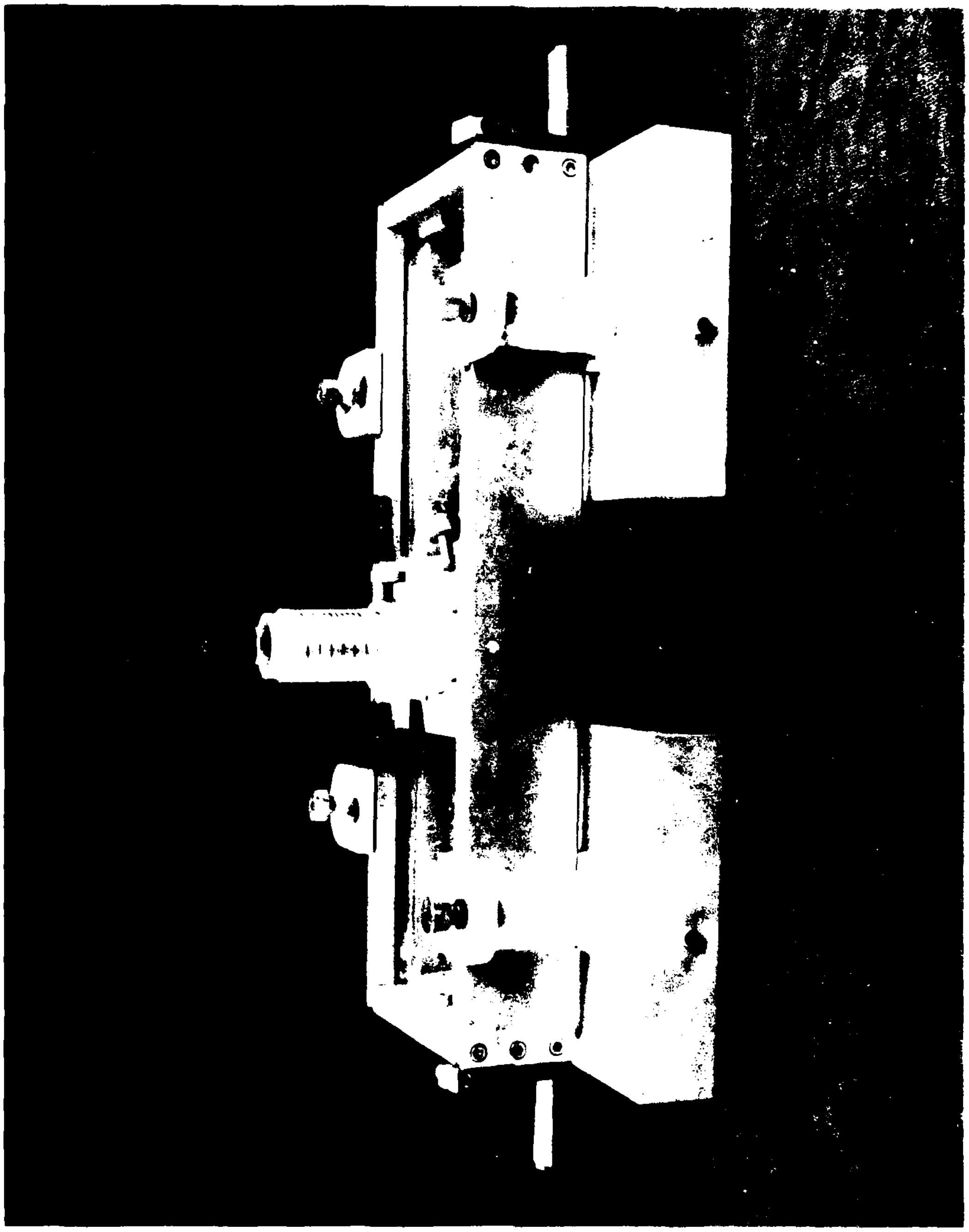


Figure 12. Ultrasonic scanner

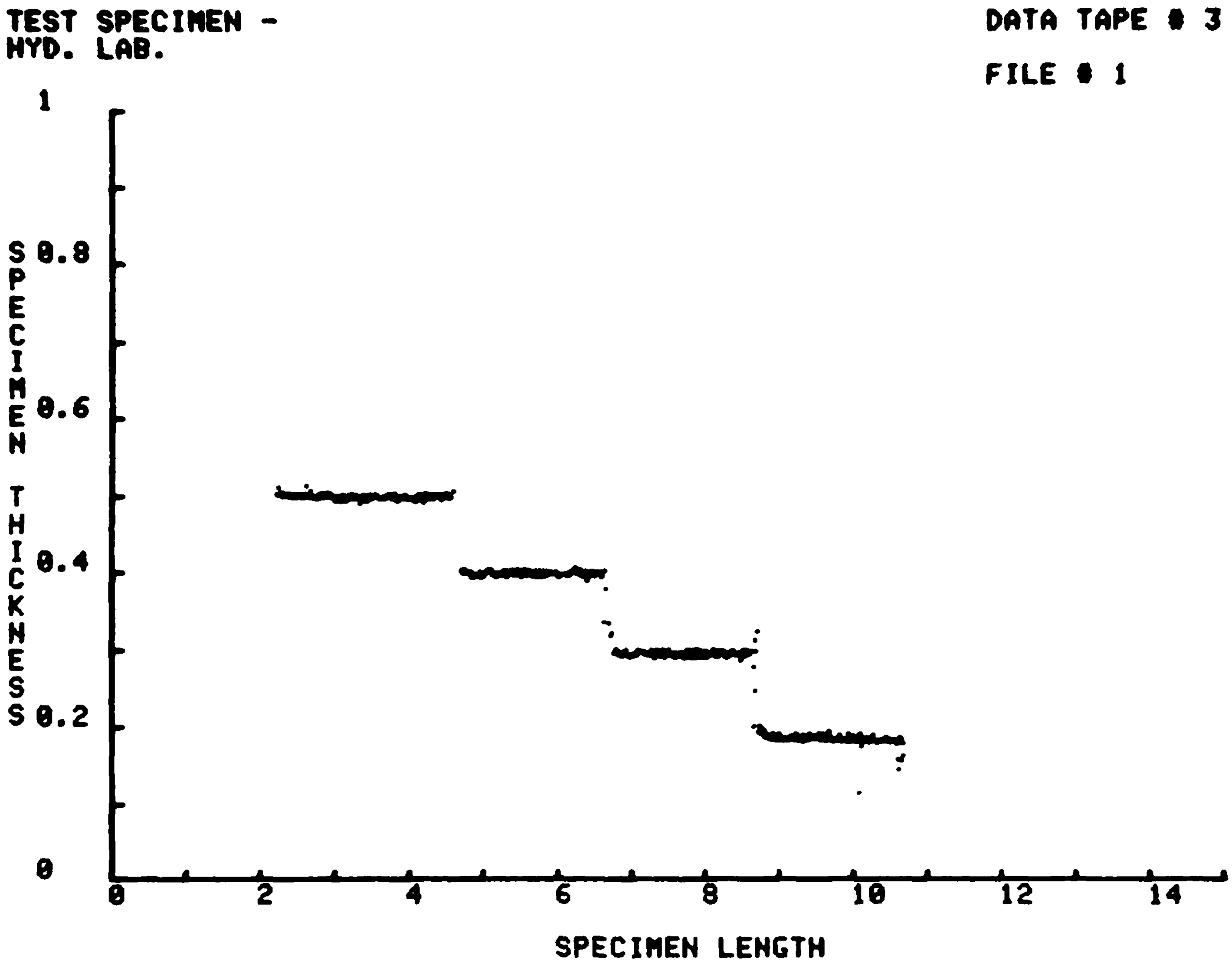


Figure 13. Ultrasonic scan of a 4-step calibration bar

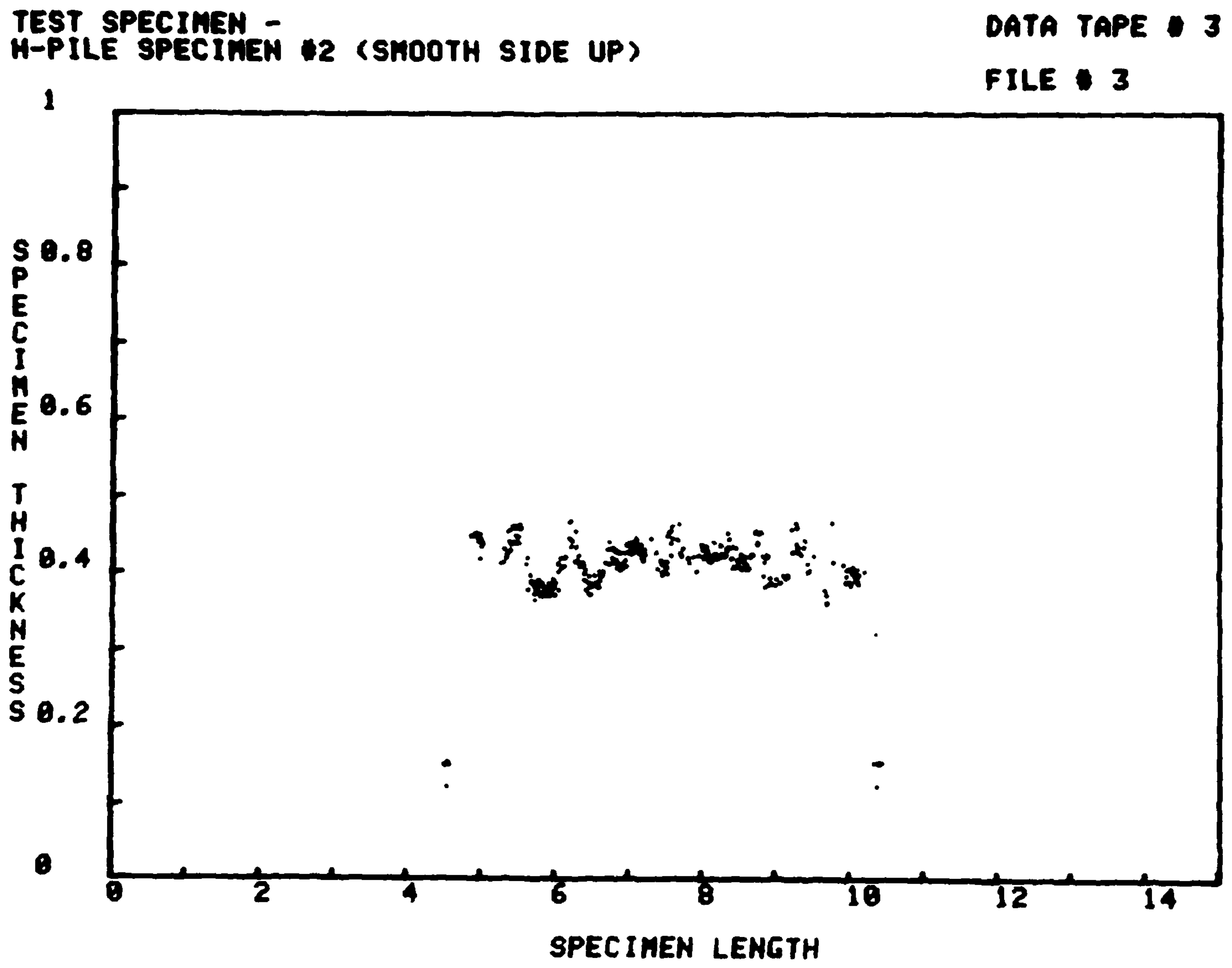


Figure 14. Ultrasonic scan of an H-pile specimen with transducer on a smooth surface.

Numerous tests conducted with the focused transducer placed over the rough surface resulted in unrecognizable "shot gun" patterns as typified by Figure 15. For tests using noncontact immersion transducers, the amplitude of the front surface echo should be approximately 70 times greater than a rear surface echo. Attempts to develop acceptance/rejection criteria using this echo amplitude measurement also failed to yield any improvement in results. This was attributed to the high degree of scattering of the ultrasonic energy by the very irregular front surface, resulting in numerous multiple front surface reflections having an echo amplitude of approximately the magnitude expected from a rear surface echo.

Underwater Surface Mill Development

At the conclusion of the series of tests discussed in the previous section, it became apparent that conventional methods of interpreting pulse echo ultrasonic data would not be capable of providing thickness measurements of severely pitted steel structures. Since the only accurate thickness readings to date had been produced from a specimen that had a smooth front surface, another specimen was prepared that had a narrow, 1/4-inch-wide slot machined in the front surface (Figure 16) to remove all the irregular features produced by pitting.

An ultrasonic scan with a 2-inch focal length transducer positioned 1 inch above this slot produced the cross-sectional plot shown in Figure 17. This plot proved accurate enough to identify individual pits found on the back surface opposite the slot. Since it would obviously be impractical to cut a sample out of each structural element to be inspected and take it to a machine shop to have a slot machined in it, an underwater milling machine was developed that would machine a 1/4-inch-wide slot in situ.

This milling adapter is designed to fit into the bridge plate of the ultrasonic scanner in the same location as the transducer to assure that the ultrasonic scan is made in the proper location. A quarter-turn, bayonet locking mechanism allows easy exchange of the transducer and the surface mill. Power for the milling operation is provided by a triple-gear, center-shaft hydraulic motor. Hydraulic input requirements are 1.5 gpm at 2,000 psi to produce an 1,800-rpm output to a four-flute, 1/4-inch-diam end mill. A vertical feed mechanism provides 0.010-inch increments in slot depth by means of a detented screw feed mechanism controlled by the depth adjustment ring shown in Figure 18.

Laboratory tests conducted with specimens prepared using the milling adapter produced acceptable cross-sectional plots when slots less than 70% of the maximum pit depth were machined in the corrosion-pitted surface. Figure 19 shows the results of milling progressively deeper slots in the front surface of a pile sample with maximum pit depths of slightly less than 0.1 inch. Figure 19a shows the cross-sectional scan of a corroded specimen with no milled slot. The large number of multiple front surface echoes makes identification of the back surface impossible. With a 0.020-inch-deep slot milled in the front surface (Figure 19b), the increased number of readings in the 0.06-inch thickness range indicates the probable location of the back wall. When the slot depth was increased to 0.040 inch (Figure 19c), the back wall

becomes evident, and a very accurate analysis of overall cross-sectional area is possible. For the purpose of these laboratory tests, the slot depth was increased to 0.060 inch (Figure 19d), which produces a very clear back surface plot with almost complete elimination of any multiple front surface echoes.

Field Testing

The first opportunity to use the ultrasonic system for an actual on-site inspection was presented when a request was received from the Naval Amphibious Base, Coronado, California, for assistance in determining the condition (including remaining wall thickness) of a 50-foot-deep diver training tank. Although this was not an inspection of actual waterfront structural elements, the inspection was valuable from the standpoint of identifying problems with remote site transportation, maintainability of the equipment, and operation of the ultrasonic scanner by divers totally unfamiliar with its function.

These tests identified two major problems with use of the laboratory system for field inspection. First, the computer system, even though it functioned properly, was very difficult to transport and set up in a location where access to the test site required hand carrying the individual components up and down stairs or ladders. Second, the guide wire for the position sensing transducer was very fragile and, once damaged or broken, was difficult to repair in the field.

The problem with the excessive size and weight of the computer system was solved by utilization of a Hewlett-Packard HP85 microcomputer, which combined the computer, CRT, hard copy print out, and data tape drive into one unit and thus reduced the weight of the system from 145 pounds to 20 pounds. Figure 20 shows the field testing instrumentation. For testing at sites where access was less restricted, a dual disk drive unit was later incorporated into the system to speed storage of data at the completion of a test. Because of the smaller CRT, slower computational speed, and graphics display, the HP85 was found to be inadequate for final analysis of the inspection data. These functions were therefore retained on the Tektronix 4052, with the HP85 used only for on-site data acquisition and raw data print out.

Field maintenance problems with the position transducer guide wire were solved by replacing the screw jack tensioning mechanism with two worm gear mechanisms (Figure 21), allowing the wire to be easily replaced and properly tensioned on site if accidentally damaged.

During tests run at the diver training tank, the ultrasonic scanner was operated by Navy divers having no previous experience with the equipment. These tests revealed that with as little as 30 minutes orientation on the proper use of the scanner and surface preparation techniques, these divers were able to efficiently calibrate and use the underwater scanning mechanism.

Field testing on actual waterfront structural elements was conducted on steel H-piles in Port Hueneme Harbor. The ultrasonic scanner was operated by Navy divers using MK I surface-supplied diving systems to allow communications with the topside ultrasonic technician. The ultrasonic unit and computer system were aboard a 70-foot diving boat.

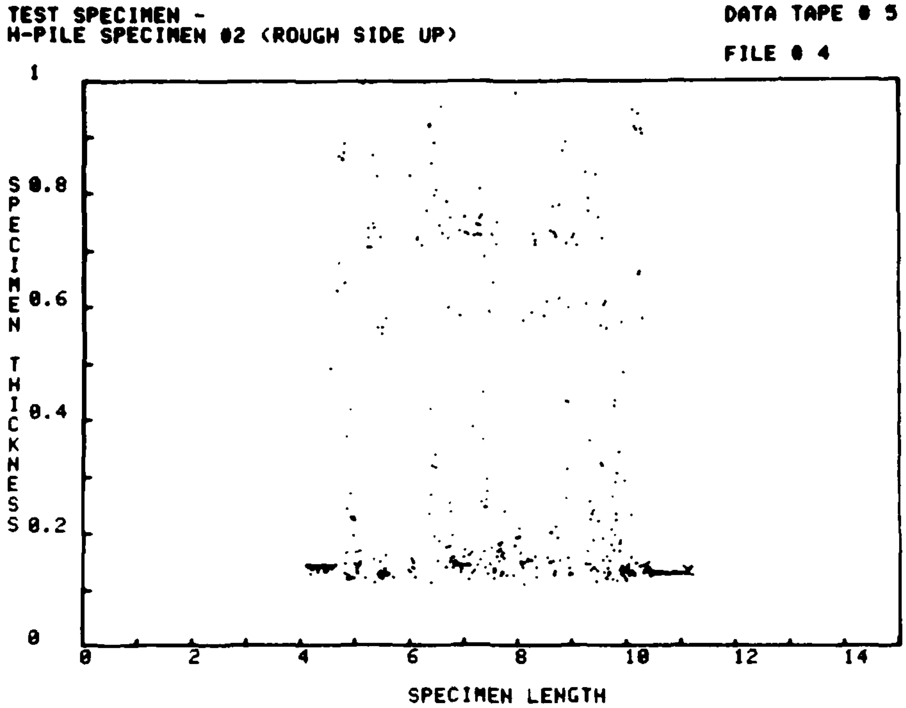


Figure 15. Ultrasonic scan of an H-pile specimen with transducer located on the rough side.

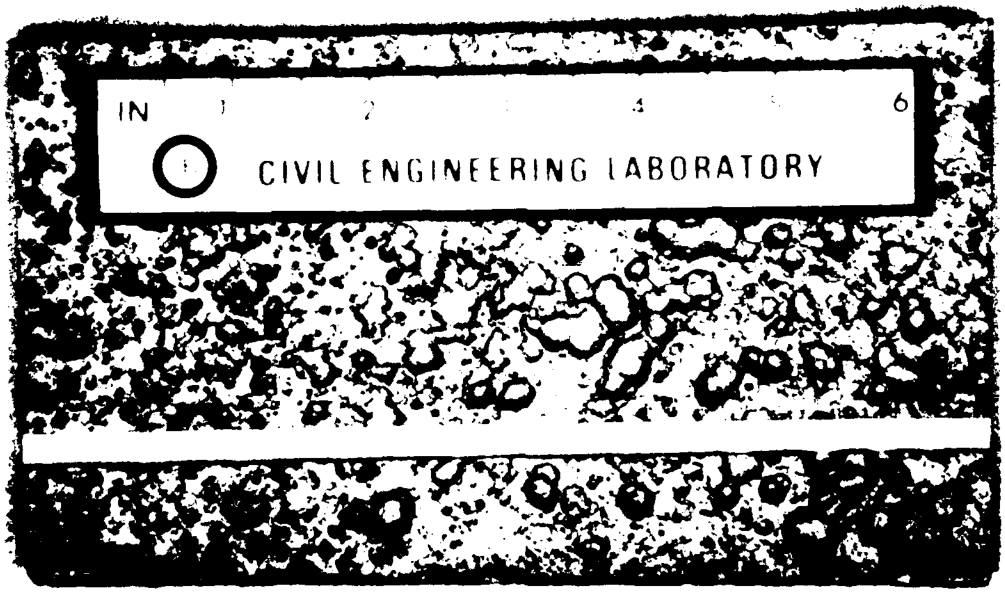


Figure 16. Corrosion-pitted test sample with 1/4-inch slot machined in the front surface.

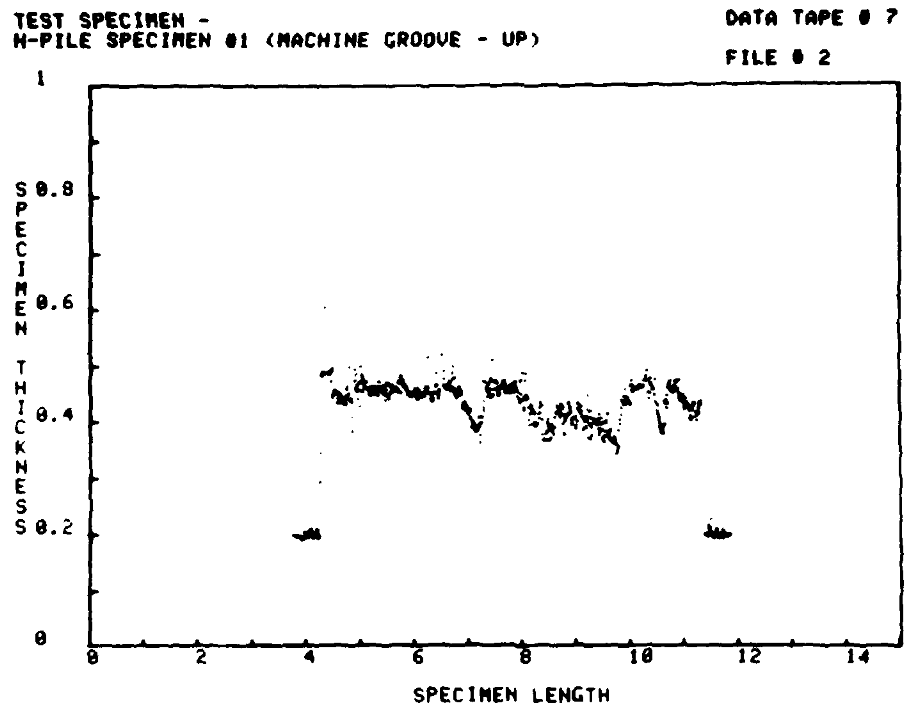


Figure 17. Ultrasonic scan of corroded H-pile along 1/4-inch wide slot machined on front surface.

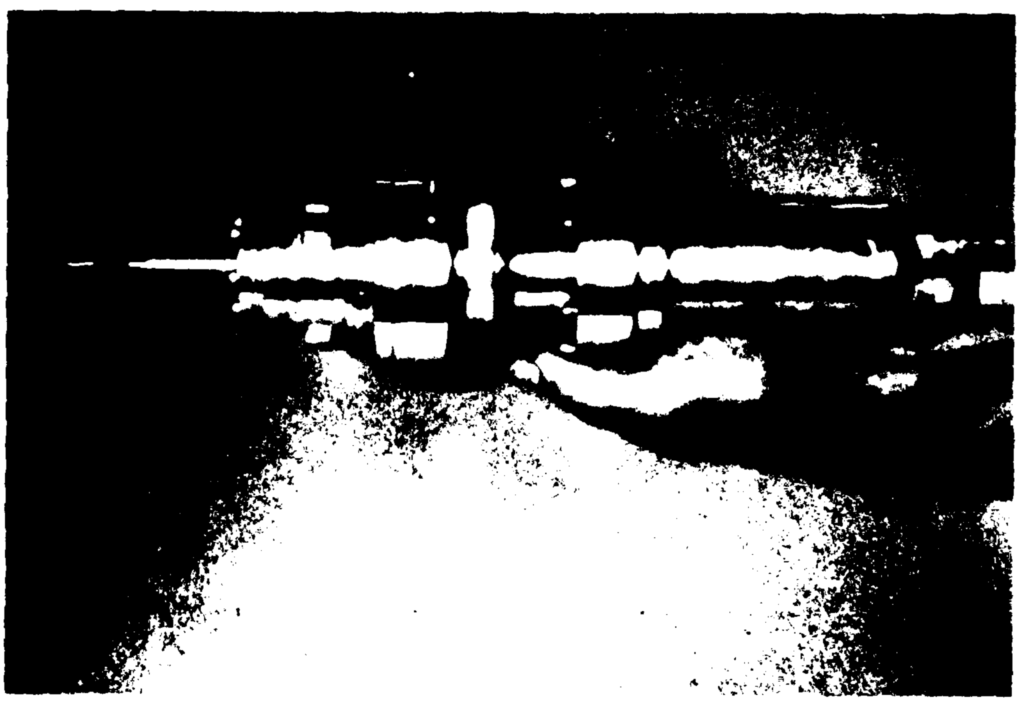
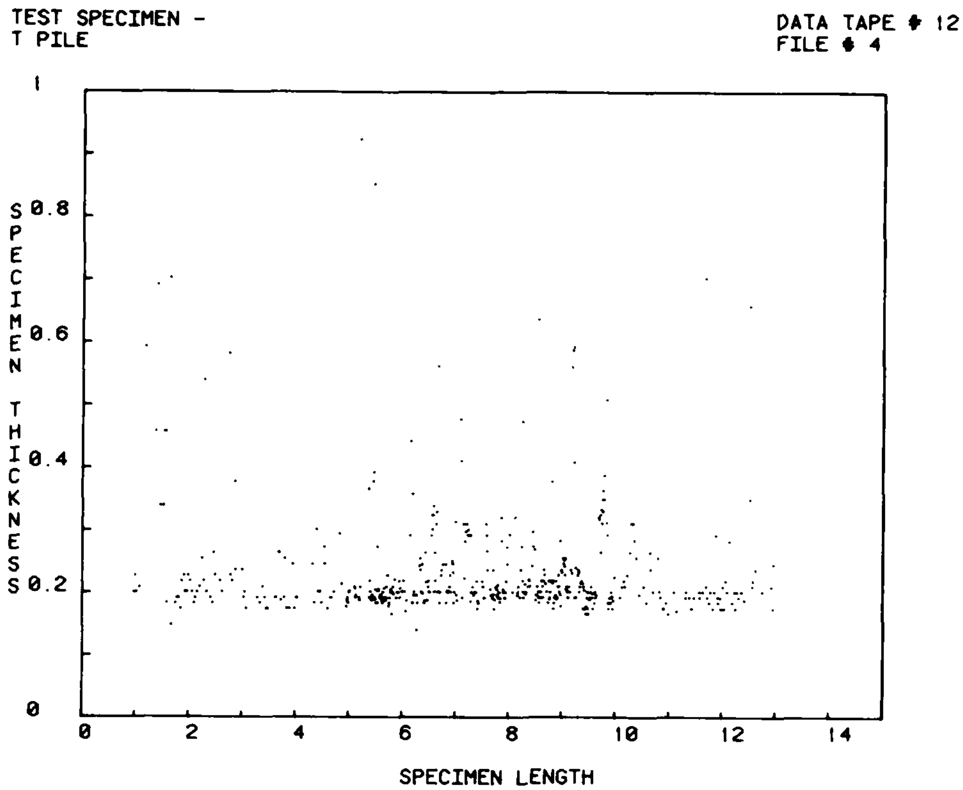
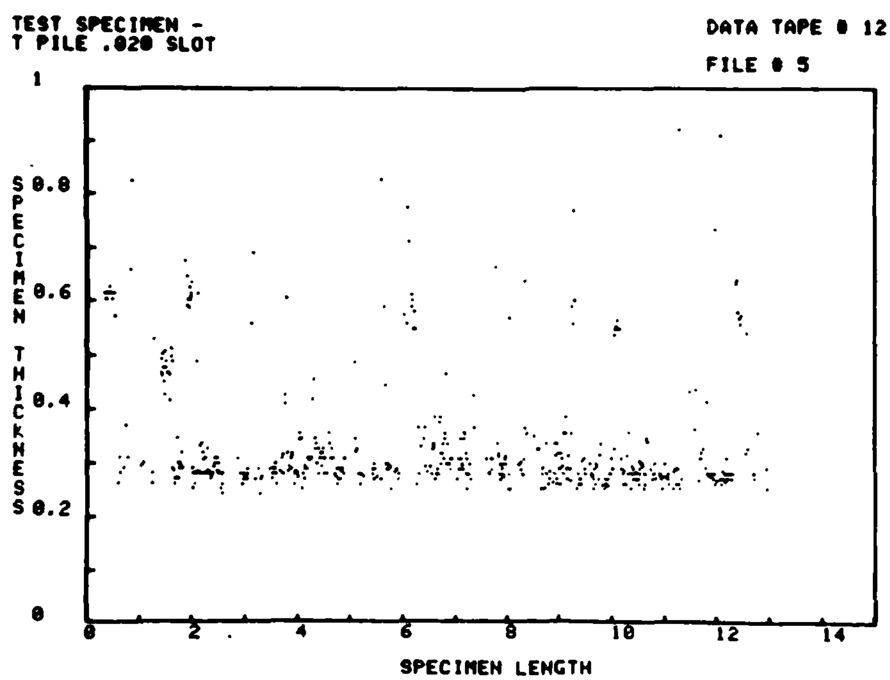


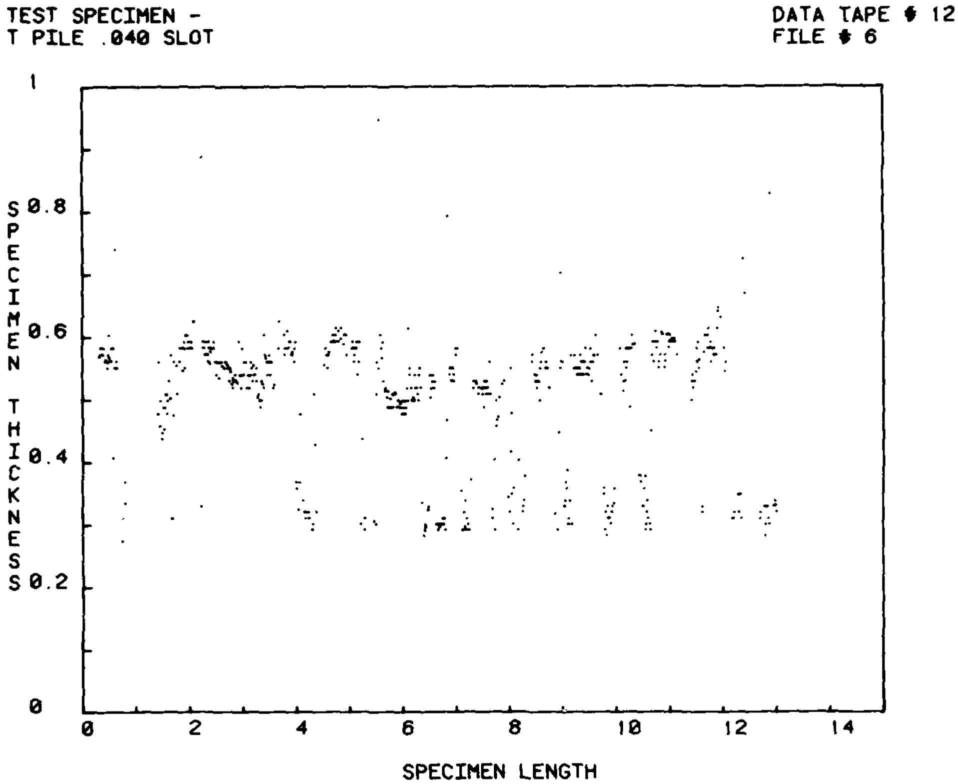
Figure 18. Hydraulic-powered end mill.



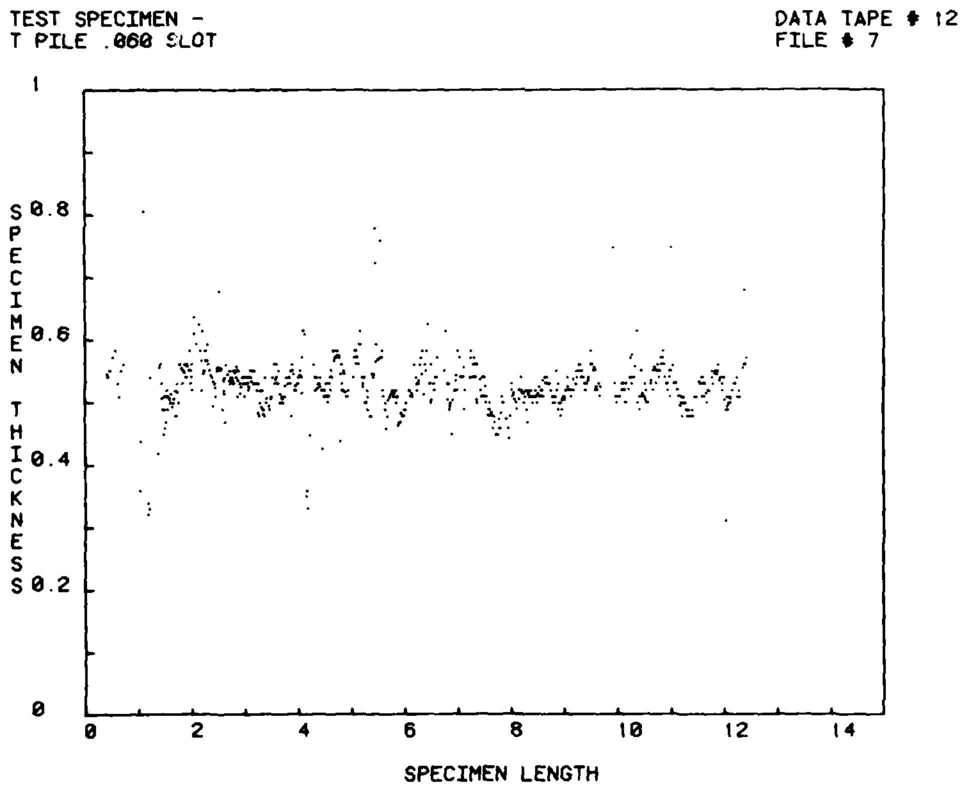
(a) No surface milling.



(b) 0.020-inch slot.



(c) 0.040-inch slot.



(d) 0.060-inch slot.

Figure 19. Ultrasonic scan of corrosion-pitted test specimen.

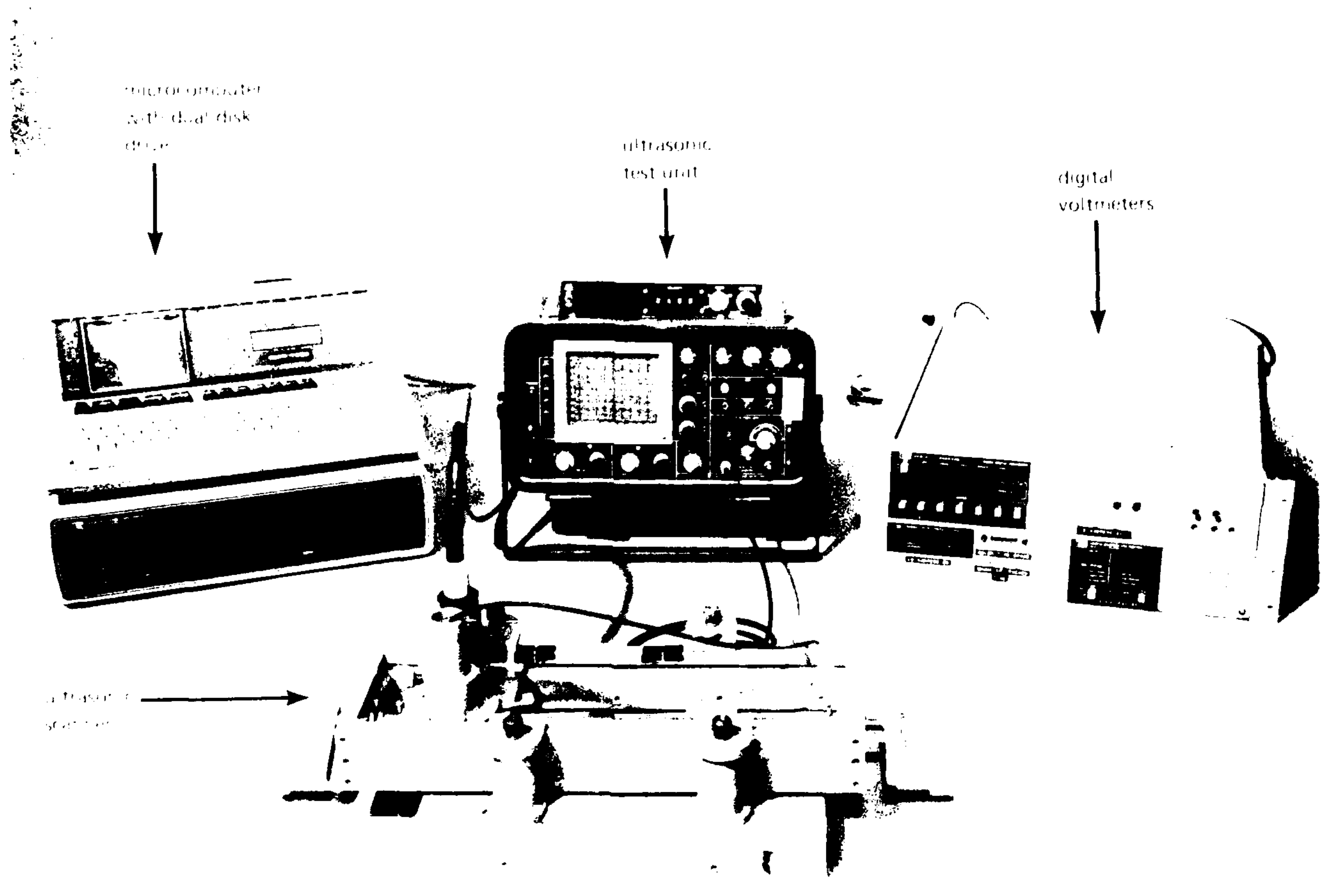
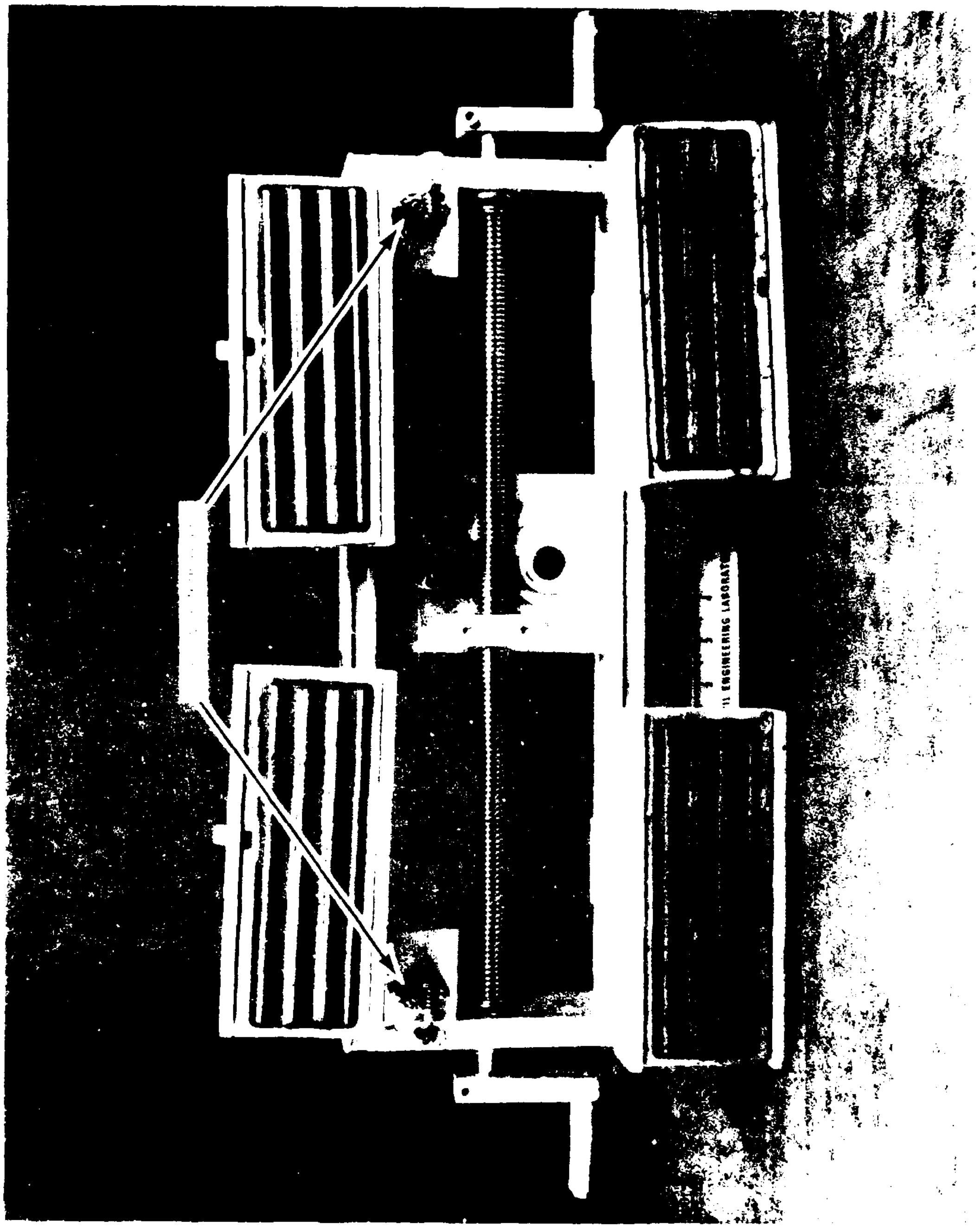


Figure 20. Instrumentation system for field testing of ultrasonic scanner



The procedure utilized during these tests was as follows:

1. Clean a 4- to 5-foot-long section of the pile flange in the area to be inspected using a high-pressure waterjet cleaning system.

2. Identify the cross section showing the greatest signs of deterioration and attach the scanner to the pile with the axis located horizontally across the face of the flange.

3. Insert the ultrasonic transducer in the scanner bridge and calibrate the system using a four-step calibration bar with thicknesses ranging from 0.200 to 0.500 inch.

4. Move the scanner bridge over the face of the pile until a complete cross-sectional scan of the pile is obtained.

5. Analyze the cross-sectional plot to determine if the back wall can be identified. If it is identified over a sufficient width of the pile to allow analysis of the average cross-sectional thickness, then the inspection is terminated at this point and the scanner is moved to a new position to conduct another test. If the back wall cannot be accurately identified, then steps 6 and 7 are repeated until an accurate cross-sectional plot is obtained.

6. Remove the ultrasonic transducer and insert the hydraulic milling tool in its place on the scanner bridge. Lower the end mill until it contacts the pile surface. Supply hydraulic power to the milling tool and advance the cutter 0.010 inch into the work surface. Move the bridge along the face of the pile to produce a 1/4-inch-wide slot along the entire width.

7. Remove the milling tool and reinstall the ultrasonic transducer. Rescan the pile as described in steps 4 and 5.

During the initial harbor tests of the scanner system, it was noted that calibration of the equipment was much more difficult then during previous tests conducted in the laboratory or shallow water diving tank. This was due to a very low signal-to-noise ratio of the back wall echo signal in the region between the front surface and transit times corresponding to approximately 3/8-inch thickness. The increase in near surface noise made it difficult to visually interpret back wall echoes less than 0.30 inch thick and completely eliminated the use of automatic data acquisition and display of thin sections.

This problem was ultimately identified as internal electrical reflections in the transducer cable caused by the impedance mismatch between the transducer and 50-ohm coaxial cable. During previous tests, relatively short cables (less than 100 feet) had been used and the electrical reflection noise had been superimposed with the front surface echo. When testing began on actual waterfront structures, longer cables (≅250 feet long) were required to reach the piling, thus extending the noise signals out into the near-surface region.

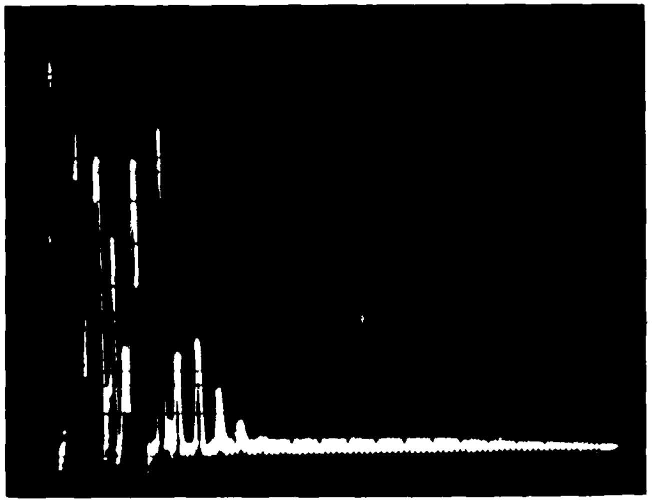
Following the procedure described by Mittleman in Reference 8, a series resistor inductor (R-L) network was placed in parallel with the transducer. The method of determining the proper values of the R-L network and the procedure for incorporating these values into the transducer cable are described in Appendix D. For the particular cable and ultrasonic transducer used in the scanning system, the best impedence matching circuit was found to consist of a 31-ohm resistor with no inductor. Figure 22 shows the difference in video signal for a 250-foot cable with and without an impedance matching network. Although this circuit resulted in a noise spike at a position corresponding to 0.08 inch, it produced the cleanest near-surface display on the CRT screen and was judged to present minimal problems with inspection of the majority of waterfront facilities.

Field tests conducted in Port Hueneme Harbor during August 1981 and May 1982 confirmed that the operation, maintenance, and logistics problems previously encountered had been solved. During 3 days of experiments, 23 tests were conducted on 8 different H-piles with no mechanical, electrical, hydraulic, or data acquisition problems. Addition of the impedance matching network to the transducer cable reduced electrical noise in the near-surface zone sufficiently to acquire adequate back wall scans without surface milling on four out of the eight H-piles tested.

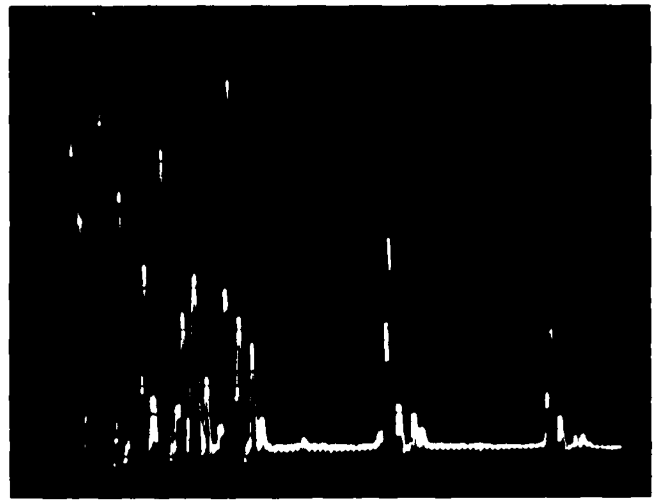
The average time to scan a pile cross section, enter facility location and test parameter data, and store the data on disk was about 10 minutes for those tests where no surface milling was required. Approximately half of that time was spent entering the facility location and test parameter data from the keyboard and storing the thickness data on tape or floppy disk. This allowed the divers to reposition the scanner on a new pile section. In most cases, the divers were ready to conduct a new thickness measurement test by the time the data acquisition system had finished storing data from the previous test. When surface milling was required to obtain plots of the back wall position, the inspection time increased by an average of 12 minutes, to a total of about 22 minutes.

SPECIFICATIONS FOR A FIELD-OPERATIONAL, UNDERWATER ULTRASONIC INSPECTION SYSTEM

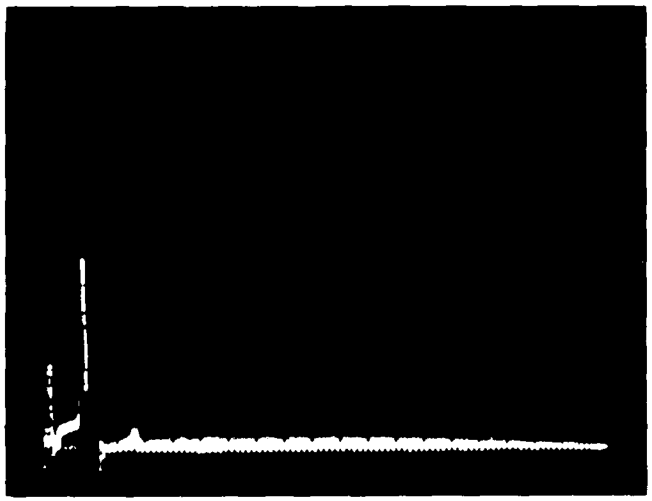
One of the major objectives of this project was to establish specifications for an ultrasonic inspection system capable of providing reliable underwater metal thickness measurements of steel waterfront structures. Although the presence of front surface pitting made it impossible to use standard metal thickness measurement techniques with off-the-shelf ultrasonic instruments, this section does provide an equipment specification and operating system software for a system composed of several commercially available components and a specialized scanner/surface milling device. This system with associated computerized data processing software is capable of producing reliable field measurements of the metal thickness of the underwater portion of steel waterfront structures.



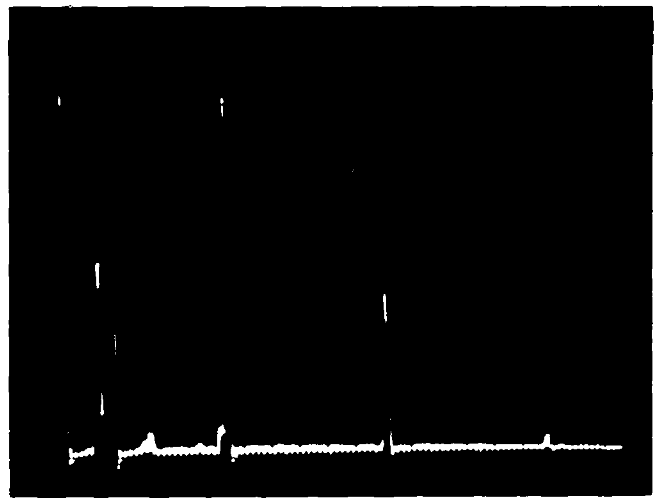
(a) 250-foot cable and transducer without impedance matching network.



(b) 250-foot cable and transducer on 0.300-inch step block without impedance matching network.



(c) 250-foot cable and transducer with 31-ohm impedance matching resistor.



(d) 250-foot cable and transducer on 0.300-inch step block with 31-ohm impedance matching resistor.

Figure 22. Ultrasonic echo display with various impedance matching networks incorporated into transducer cable.

Equipment Specification

A system used for inspection of steel waterfront structures suspected or known to have front surface pitting should consist of the following components:

1. Ultrasonic flaw detector (1 each)

2. Analog-to-digital voltmeters with IEEE 488 interface (2 each)

3. Portable microcomputer with integral tape drive and printer (1 each)

4. Ultrasonic scanner (1 each)

5. 50-ohm coaxial transducer cable with impedance matching circuit (250 feet minimum)

6. Four-conductor instrumentation cable with waterproof connectors (250 feet minimum)

7. Ultrasonic transducer (1 each)

8. Hydraulic-powered end mill (1 each)

9. Hydraulic power source (1 each)

Detailed specifications and interfacing requirements for each of these components are presented in Appendix E.

Data Acquisition and Analysis Software

Software developed to support the automatic data acquisition and analysis system for underwater metal thickness measurement consists of three programs:

- System calibration

- Ultrasonic scanning

- Data print out and analysis

The calibration and scanning programs have been written in Advanced BASIC for both the Tektronix 4052 and Hewlett-Packard HP85A. The data print out and analysis program was developed only for the Tektronix 4052. A brief description, logic flow chart, and program listing for each of these three programs are presented in Appendix F.

CONCLUSIONS

Based on the laboratory testing and field evaluation of pulse echo ultrasonic inspection equipment, the following conclusions can be drawn regarding the suitability of this technique for underwater inspection.

1. Because of multiple front surface echoes from corrosion-pitted steel surfaces, it is generally not possible to obtain reliable metal thickness measurements using a digital ultrasonic thickness instrument. In specific, limited situations, the digital thickness equipment may provide acceptable data. These situations include use of a CRT display in addition to the digital readout to provide visual clues to the nature of the received echoes and operation of the equipment by an ultrasonic technician with experience in inspecting corroded steel structures.

2. The use of a computerized data acquisition and calibration system can improve the accuracy and significantly reduce the operator training requirements of the metal thickness measurement on specimens with a smooth front surface by as much as an order of magnitude when compared to visual interpretation of the CRT-displayed echo signal or readings from a digital thickness gage.

3. An ultrasonic scanner and milling adapter have produced acceptable cross-sectional plots and average thickness measurements by first smoothing the front surface and then conducting the thickness scan using a focused ultrasonic transducer. This technique is not truly nondestructive, however, since it requires removal of some of the structural material to produce accurate thickness measurements.

4. Analysis of possible electrical safety problems with the ultrasonic instrument has shown that even in the event of a catastrophic failure the voltages and currents to which the diver would be subjected are not in excess of those considered safe. However, problems were encountered with differences between the utility system ground and seawater ground potentials. A power system test circuit has been developed that allows this problem to be detected and corrected prior to commencing diving operations.

5. The required length of cable between the ultrasonic instrument and transducer for inspecting waterfront structures results in excessive front surface noise due to the impedance mismatch between the cable and transducer. A series resistor-inductor network connected in parallel with the transducer significantly reduces noise levels in this near-surface area.

6. The equipment and procedures described in this report produced inspection rates of 6 piles per hour for scans requiring no surface milling and 3 piles per hour with milling. It is anticipated that continued advances in microcomputer technology and streamlining of the data acquistion software could result in at least a twofold increase in this inspection rate within the next 2 to 3 years.

RECOMMENDATIONS

1. Due to the problems associated with multiple front surface echoes, digital ultrasonic thickness gages should not be used as the only means of inspecting steel structures in areas found to have irregular front surface conditions or where the thickness readings are found to fluctuate rapidly over a small area.

2. Field tests of the ultrasonic scanner and surface milling adapter have confirmed that results comparable to those obtained during laboratory tests are attainable during in-situ inspection of steel pilings.

3. Since the ultrasonic scanner and milling adapter technique is not truly nondestructive in nature, it should be considered an interim inspection procedure. Investigation of alternative inspection techniques initiated in 1982 that do not require material removal should be continued.

4. A power system test circuit as described in Appendix C should be incorporated into any 110-VAC circuit used to power underwater ultrasonic test equipment. As an additional safety precaution, inspection divers should be required to wear neoprene wetsuit gloves and should be instructed not to reach through the air/water interface while holding any grounded electronic equipment in their hands.

5. A series resistor-inductor network connected in parallel with the ultrasonic transducer should be incorporated into all cables greater than 100 feet in length to minimize near-surface noise due to electrical impedance mismatching.

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APPENDIX A
STRUCTURAL ANALYSIS CRITERIA

The following material has been extracted from Ref 2 and edited to present only those portions of the material relating to inspection of steel structures.

For a given structural element, both material strength and geometry may change with time. However, for this initial definition of inspection data criteria, only the element geometry is emphasized as a parameter for inspection. This, under normal conditions, is an acceptable approach for steel elements. It appears less acceptable for concrete and timber elements, because of the potential for changes in strength of these material with time.

The structural resistance (or capacity) of an element can be expressed by equations of the form:

$$R = F \cdot G \qquad (1)$$

where R represents the structural resistance, F is a limiting unit stress, and G is a function of the element's geometry. The specific forms of Equation (1) depend on the nature of the loading (axial load, bending moment, etc.), the material, and the failure mode being considered (material overstressing or buckling).

Definition of General Accuracy Requirements

The strength of materials has been shown to be random (Ref 8). It follows then that the structural resistance must also be random. Furthermore, the accuracy of an estimate of an element's structural resistance will be dependent on the accuracy of the material strength estimate. In the inspection of existing construction, the accuracy of the resistance estimate will also depend on the accuracy of the measured field data. The relationship between these two accuracies and the definition of the desired accuracy of the field data are presented in this section.

A measure of the dispersion or variability of a random variable relative to the central or mean value is the coefficient of variation (COV) which is computed by

$$\delta_x = \frac{\sigma_x}{\mu_x}$$

where δ_x is the COV, σ_x is the standard deviation, and μ_x is the mean value of x.

Considering the terms of the general resistance equation, Equation A-1, to be random variables, the COV of the structural resistance is given by

$$\delta_r = (\delta_f^2 + \delta_g^2)^{1/2} \qquad \text{(A-2)}$$

where δ_r, δ_f, and δ_g represent the COV of the resistance, strength and geometry, respectively.

For new construction, the COV of the geometry can be considered to be insignificant, so that normally

$$\delta_r = \delta_f$$

For existing construction where deterioration has occurred and the geometry (or amount) of the remaining material must be measured, the COV of the geometry term will not be insignificant. It can be defined based on the current capability for field measurements or by specifying δ_g or a value for the COV of the resistance predictions for the altered structure, denoted by δ_{ra}, and then computing δ_g utilizing Equation A-2. The latter is the approach taken here. The results are shown in Table A-1 which lists the values of δ_f, δ_g, and δ_{ra} used in the subsequent discussion.

For this study it is assumed that the accuracy of the material strength estimate remains unchanged. If the strength properties are measured, the desired accuracy would be expected to equal the value of the COV in the first column of Table A-1.

Based on these values of the COV for the geometry term (Table A-1), the required accuracy (i.e., the required COV) of the field measurements can be determined. For the case of material overstressing, the required COVs for the different loading conditions and materials are given in Table A-2. These values were computed as follows:

> Consider a steel element under axial load. For this case,
> G = A (Equation A-1)
>
> The required COV of the area measurements is
> $\delta_a = \delta_g = 0.09$ (from Table A-1)
>
> Also, $A = Kd^2$
> where d represents a linear dimension.
>
> Therefore,
>
> $\delta_a = 2\delta_d$
>
> or $\delta_d = 0.04$

The other values given in Table A-2 were computed in a similar manner.

Piles. For piles, the predominate load is an axial compressive load. Deterioration reduces the net cross-sectional area, which may either increase the unit axial stress to the point where the material fails in compression, or reduce the stiffness of the pile to the extent that a local or general instability failure occurs.

For the tubular pile and H-pile with uniform reduction in cross-section, the failure mode is expected to be by material overstressing, irrespective of the length of the damaged section. Stability failures may be critical for the composite pile and the H-pile when deterioration of the flange width predominates.

The data accuracy requirements as given in Table A-4 were derived using Table A-2 or A-3, depending on the expected failure mode. For the H-pile with "uniform" deterioration, the accuracy of the flange width and thickness measurements should be, from Table A-2, $\pm 4\%$. If it can be determined that the flange width is unchanged from the original state, then the accuracy of the thickness measurements can be increased to $\pm 8\%$. When the deterioration is

predominantly a reduction of flange width and it has occurred over a length greater than approximately 20% of the unsupported pile length, then, from Table A-3, the accuracy requirements are similar to the previous case except that the length of the damaged section should be determined so that the COV is 2%.

For the tubular pile, and a composite pile with a damaged section less than 30% of the length, the accuracy of the thickness measurement was obtained from Table A-2 using the areal limit because the shell thickness is the principal variable in computing the area. For the composite pile with a long damaged region, the accuracy requirements are based on the data in Table A-3.

Table A-1. Coefficient of Variation

Material	δ_f	δ_g [a]	δ_{ra} [a]
Steel	0.08[b]	0.09	0.12
Concrete	0.12[b]	0.15	0.19
Wood	0.20[c]	0.20[d]	0.29

[a]Values derived as shown in Appendix A.

[b]Value based on information from Reference 5.

[c]Value based on data presented in Reference 6.

[d]Computed value was 0.21 (Appendix A) and was revised to 0.20.

Table A-2. Required Coefficient of Variation Based on Material Strength

Loading	Geometry	Material		
		Concrete	Steel	Timber
Axial Load	Areal	0.15	0.09	0.20
	Linear	0.08	0.04	0.10
Bending Moment	Section Modulus	0.15	0.09	0.20
	Linear	0.05	0.03	0.07
Shear	Areal	0.15	0.09	0.20
	Linear	0.08	0.04	0.10

Table A-3. Coefficient of Variation for Columns

Material	δ_{rc} [a]	δ_E	δ_ℓ [b]	δ_d	δ_a
Steel	0.12	0.05 [c]	0.02	0.04 [d]	0.08
Concrete	0.19	0.12 [c]	0.02	0.07 [e]	0.14
Timber	0.29	0.22 [f]	0.02	0.07 [d]	0.14

[a] δ_{rc} is equal to δ_{ra} (Table 11).

[b] Assumed value, based on premise that accuracy of ±0.25 ft in 15 ft is reasonable; $\delta_\ell = 0.25/15 \simeq 0.02$.

[c] Assumed value.

[d] Value computed using Equation 18.

[e] Value for R/C piles computed using the following equation:

$$\delta_{rc} = 5(\delta_d)^2 + \delta_f^2 + \delta_\ell^2$$

This equation is based on the long column equation for R/C columns, Table 2; δ_f is equal to 0.12, as presented in Table 3. For prestressed concrete pile, Equation 18 was used; results, however, were the same.

[f] Value obtained from Reference 6.

Table A-[illegible]. Data Requirements

Element	Structural Evaluation Criteria	Field Condition	Field Data Required: Parameter	Range	Accuracy[a]	Measurement Location
STEEL PILES Cross Section	Material strength (Table 9)	Uniform reduction of thickness, $0 < a/L < 1$	t_f, t_w	3/8 to 1 in.	4[b]	(1) Tidal zone (2) Mid-region of pile length (3) Regions adjacent to sections of concrete cover (4) Most deteriorated section
			b_f	6 to 15 in.	4[b]	
	Stability about x-x axis (Table 2)	Reduction of flange width predominant, $a/L < 0.2$	L_d	up to 15 ft	20	
			H_d	up to 25 ft	20	
	Stability about y-y axis (Table 2)	Reduction of flange width predominant, $a/L > 0.2$	t_f, t_w, b_f, H_d	same as above	same as above	
			L_d	~15 to 50 ft	2	
Hollow Tube	Material strength	Reduced shell thickness, $0 < a/L < 1$	t_s	3/8 to 1 in.	9	
			L_d	up to 15-20 ft	20	
			H_d	up to 25 ft	20	
Composite	Material strength	Reduced shell thickness, $a/L < 0.3$				
	Stability	Reduced shell thickness, $a/L > 0.3$	t_s	3/8 to 1 in.	4	
			H_d	same as above	20	
			L_d	~ 20 to 50 ft	2	

continued

Table A-4. Continued

Element	Structural Evaluation Criteria	Field Condition	Field Data Required			
			Parameter	Range	Accuracy[a]	Measurement Location
	Integrity of protective cover: concrete does not contribute to load-carrying capacity		A_{es}	--	20	Areas in which spalling has exposed steel
			t_s	--	as noted in cases above	
			W_c	<1/32 in.	20	Areas showing rust stains
			ℓ_c		20	

[a]Given in terms of the COV.

[b]*If* b_f *is observed to be original size,* accuracy of t_f, t_w can be increased to 8%.

Table A-[illegible]. Data Requirements

Element	Structural Evaluation Criteria	Field Conditions	Field Data Required: Parameter	Range	Accuracy[a]	Measurement Location
<u>TIED BULKHEAD</u> Sheet Piling Steel (Z)	Moment resistance (normally, Z-section) $f_b = M/S$ (Table 9)	(1) Corrosion of sheet pile				(1) Maximum moment section (1/4 to 1/2 of water depth, MLW, from bottom)
		(a) Change in metal thickness	t_f	1/4-1 in.	9	
			t_w	1/4-1 in.	9	(2) Water surface region or just below concrete protective cover
		(b) Size & location of damaged area	H_d, L_d	0-20 ft	20	
			W_d	0-30 in.	10	(3) Most severely damaged area based on visual observations
		(c) Change in embedment depth	d_b	20-60 ft	20	(1) In vicinity of pile base, within $(d_b/2)$
	Punching shear around tie (Table 9) <u>INTERNAL WALE ONLY</u> $\nu_s = T/A_v$	(1) Corrosion around tie				(1) Corroded regions within 3 d_w of tie
	ν_s = shear stress	(a) Change in sheet thickness	t_s	1/4-1 in.	4	
	T = force in tie A_v = area in shear	(b) Diameter of circle of minimum thickness readings or d_w	d_c		4	

continued

Table A-4. Continued

Element	Structural Evaluation Criteria	Field Conditions	Field Data Required			
			Parameter	Range	Accuracy[a]	Measurement Location
	Soil retention	(3) Joint separations	W_j	0 to 3 in.	20	
			ℓ_j	<0.5 ft	20	
Tie-Steel	Axial tensile strength $f_t = T/A_r$ (Table 9)	(1) Changes in tie	A_r	0.5-2.0 in.^{2}	9	(1) Vicinity of seaward end
		Condition at seaward end; presence of corrosion; condition around nut.	T_r	25-100 kips	12	(2) Seaward end of tie
			--	--	--	
Wales a. Steel	Moment resistance $f = M_c/T = M/S$ (Table 9)	(2) Corrosion of steel wale	t_f	1/4-1 in.	9	(1) At tie (2) Mid-point between ties
			t_w	1/4-1 in.	9	(3) Most severely damaged section based on visual observations
		Location of corrosion relative to tie	D_{td}	0-20 ft	20	
		Condition of splices				
b. Timber	Moment resistance $f = M/S$	(1) External damage	b	8-12 in.	7	(1) At tie (2) Mid-point between ties
			h	8-12 in.	7	(3) Most damaged section
	Shear resistance $\nu = v/A$ (Table 9)	(2) Internal damage	A_r	70-150	20	

continued

Table A-4. Continued

Element	Structural Evaluation Criteria	Field Conditions	Field Data Required			
			Parameter	Range	Accuracy[a]	Measurement Location
Anchorages	Resistance to tie force - horizontal load resistance	Indications of anchor movement: (a) Cracking of pavement (b) Bowing/movement of bulkhead (c) "Low" force in tie				

[a]Accuracy in terms of the COV (%).

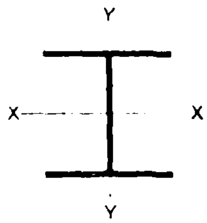
NOMENCLATURE FOR TABLE A-4

A_r	Remaining cross-sectional area
A_o	Original cross-sectional area
L_d	Length of damaged section
H_d	Location of damaged section along pile length, distance from pile cap or seabed to of damaged section
L	Unsupported length of pile
t_f	Flange thickness
t_w	Web thickness
W_d	Width of damaged section
d_b	Depth to seabed
t_s	Sheet thickness
d_c	Diameter
w_j, l_j	Width and length of joint separation in steel sheet piles
A_r	*Cross-sectional area of the rod*
T_r	Tension in tie rod
D_{td}	Distance from t_{re} to of corroded region
t_s	Steel thickness
A_{es}	Area of exposed steel
w_c	Widty of crack in concrete
l_c	Length of crack in concrete
d_c	Depth of crack in concrete
A_{sr}	Remaining cross-sectional area of steel reinforcement

APPENDIX B
PROPERTIES AND CONFIGURATION OF STANDARD H-PILING AND SHEET PILING

H-PILE PROPERTIES

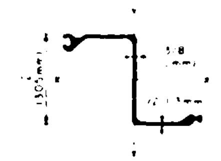
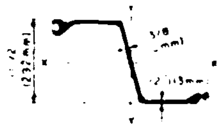
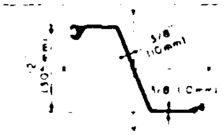
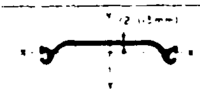
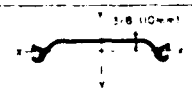
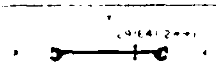
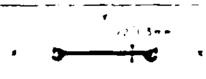
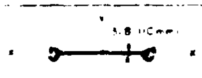
H-Piles Properties



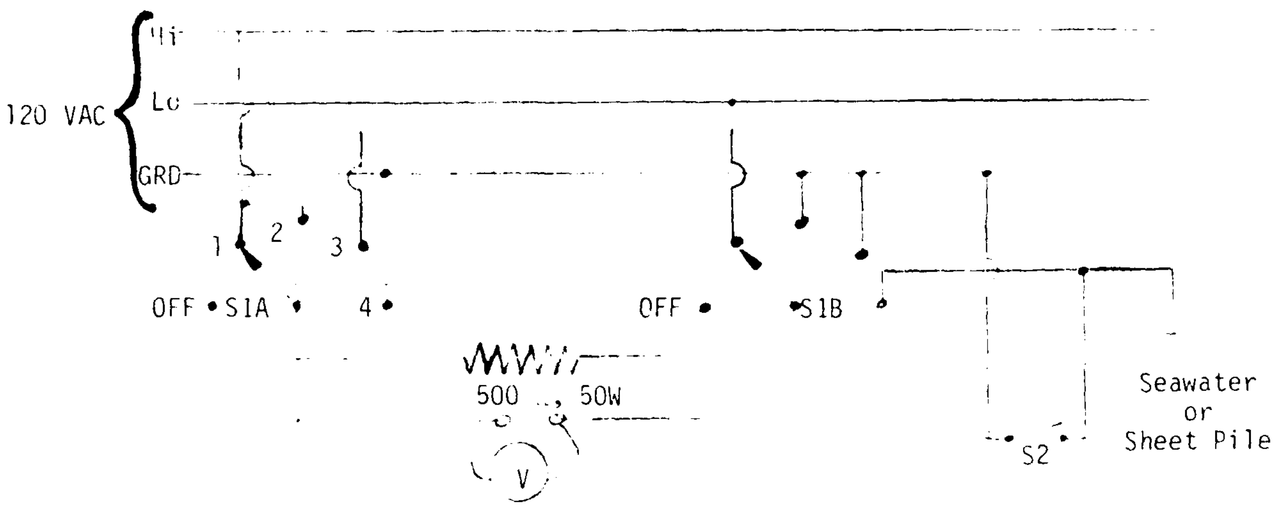
Properties for Designing–U.S. Units

DESIGNATION AND NOMINAL SIZE	WEIGHT PER FOOT	AREA	DEPTH d	FLANGE WIDTH b	FLANGE THICKNESS t	WEB THICKNESS w	FILLET RADIUS R	SURFACE AREA	AXIS X-X I	AXIS X-X S	AXIS X-X r	AXIS Y-Y I	AXIS Y-Y S	AXIS Y-Y r
inch	lb	$inch^2$	inch	inch	inch	inch	inch	ft^2/ft	$inch^4$	$inch^3$	inch	$inch^4$	$inch^3$	inch
HP14 14 x 14½	117	34.4	14.21	14.885	.805	.805	.60	7.11	1220	172	5.96	443	59.5	3.59
	102	30.0	14.01	14.785	.705	.705	.60	7.06	1050	150	5.92	380	51.4	3.56
	89	26.1	13.83	14.695	.615	.615	.60	7.01	904	131	5.88	326	44.3	3.53
	73	21.4	13.61	14.585	.505	.505	.60	6.96	729	107	5.84	261	35.8	3.49
HP12 12 x 12	74	21.8	12.13	12.215	.610	.605	.60	5.90	569	93.8	5.11	186	30.4	2.92
	53	15.5	11.78	12.045	.435	.435	.60	5.82	393	66.8	5.03	127	21.1	2.86
HP10 10 x 10	57	16.8	9.99	10.225	.565	.565	.50	4.91	294	58.8	4.18	101	19.7	2.45
	42	12.4	9.70	10.075	.420	.415	.50	4.83	210	43.4	4.13	71.7	14.2	2.41
HPS10 10 x 8	57	16.8	10.16	8.320	.650	.650	.50	4.28	287	56.4	4.13	62.6	15.1	1.93
	42	12.3	9.82	8.150	.480	.480	.50	4.20	203	41.3	4.06	43.4	10.7	1.88
HP8 8 x 8	36	10.6	8.02	8.155	.445	.445	.40	3.92	119	29.8	3.36	40.3	9.88	1.95

STANDARD SHEET PILING

DESIGNATION	PROFILE	INTERLOCK	WEIGHT PER LINEAR FT (LB)	WEIGHT PER SQ FT OF WALL (LB)	AREA A (INCH²)	DRIVING WIDTH (INCH)	SECTION MODULUS PER FT WALL (INCH³)	SECTION MODULUS PER PILE (INCH³)
PZ38		INTERLOCK WITH EACH OTHER AND PSA 23 PSA 28	57.0	38.0	16.8	18	46.8	70.2
PZ32			56.0	32.0	16.5	21	38.3	67.0
PZ27		INTERLOCKS WITH ITSELF AND PSA 23, PSA 28	40.5	27.0	11.9	18	30.2	45.3
PDA27		INTERLOCK WITH EACH OTHER	36.0	27.0	10.6	16	10.7	14.3
PMA22			36.0	22.0	10.6	19⅝	5.4	8.8
PSA28			37.3	28.0	11.0	16	2.5	3.3
PSA23			30.7	23.0	9.0	16	2.4	3.2
PSX32		INTERLOCK WITH EACH OTHER	44.0	32.0	13.0	16½	2.4	3.3
PS32			40.0	32.0	11.8	15	1.9	2.4
PS28			35.0	28.0	10.3	15	1.9	2.4

APPENDIX C
POWER SYSTEM TEST CIRCUIT



The circuit shown above was developed to determine if potentially dangerous voltages exist on low voltage power systems at diver work sites. The 500 ohm resistor simulates the approximate resistance a diver with wet hands would have. The voltmeter should be capable of accurately measuring to ± 0.1 volts. To test the power system for improper wiring or high resistance grounds, S2 is switched off (open). With S1 in position 1, the meter should display power line voltage. With S1 in position 2, line voltage should again be measured. If the meter does not read the same voltage (± 0.1 V) as in position 1 either the ground circuit has a high resistance connector or the Hi and Lo wires are reversed in the power system. By selecting position 3 on S1, the problem can be further isolated. If line voltage is measured with S1 in position 3, then the Hi and Lo wires are reversed and the problem should be corrected. If a voltage different from line voltage is measured then the ground circuit resistance can be calculated from equation 1.

$$R_{grd} = \frac{V_{pos\ 1} - V_{pos\ 3}}{V_{pos\ 3}} (500) \qquad (1)$$

If R_{grd} is greater than 1 ohm the ground circuit should be checked for bad connections. With S1 in position 4, any potential difference between seawater and utility system ground will be measured. If this voltage exceeds approximately 6 volts the power system is not at ground potential and should be checked. For voltage less than 6 volts, closing S2 will provide a ground path for temporary use but the power system ground should be checked for bad connections.

Appendix D

ELECTRICAL IMPEDANCE MATCHING FOR ULTRASONIC TRANSDUCER CABLES

Underwater ultrasonic inspection of steel waterfront structures often requires the use of transducer cables considerably longer than the 100-foot maximum length recommended by most instrument manufacturers. Experience gained during the development of the underwater ultrasonic scanner indicates that cable lengths of 250 feet will probably be required for inspection of most steel waterfront piers and wharves. When cables greater than 100 feet in length are used between the ultrasonic instrument and transducer, signals generated due to the electrical impedance mismatch between the cable and transducer will result in an extremely noisy near-surface region of the CRT display. This noise not only makes it difficult to visually discriminate back wall echoes for specimens with thicknesses less than 3/8 inch, but also makes it impossible to accurately produce a digital thickness readout.

Analysis of the major components of the ultrasonic system indicated that the largest impedance mismatch occurred between the cable and transducer. To match these impedances a series resistor-inductor (R-L) network was connected in parallel with the transducer. At an operating frequency of 5 MHz the proper components of the R-L network are determined from the following equations:

$$L = Z_o^2 C/(1 + Z_o^2 W^2 C^2) \tag{1}$$

$$R = Z_o/(1 + Z_o^2 W^2 C^2) \tag{2}$$

where

L = inductance (H)

R = resistance (ohms)

Z_o = system impedance (ohms)

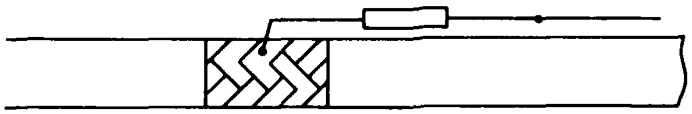
C = transducer capacitance (F)

W = angular frequency (Hz)

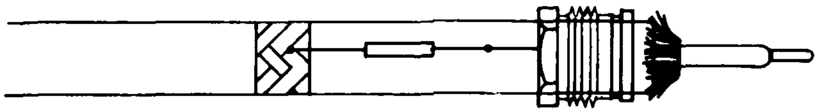
For the ultrasonic system being developed at NCEL, Z_o = 50 ohms and $w = \pi \times 10^7$ Hertz.

Since this information on the capacitance of the transducer was not readily available from the manufacturer, the IBK 5-2D transducer was tested with a General Radio Company Impedance Bridge (Type 1650-S) and found to have a capacitance of 498 pF. Using Equations 1 and 2, the R-L network will require a 31.02-ohm resistor and a 0.772-μH inductor to produce an impedance to 50 ohms. Since the value of the inductor is so small, it was concluded that the effect on the R-L circuit is negligible, and only a resistor would be needed to make the impedance matching circuit. To experimentally confirm the calculations and the assumption of the negligible effect of the inductor, various R-L circuits were tested with the IBK 5-2D transducer. Common values of resistors ranging from 10 to 75 ohms, inductors from 0.50 μH, and RG-58 cable lengths of 9 feet, 100 feet, and 250 feet were used.

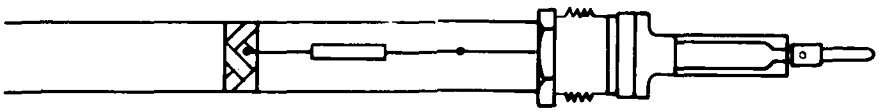
Scanning tests were conducted with different R-L networks and resistors at each length of cable using a 4 by 5-inch H-pile section as the scanning target. Scanning data taken by the computer were compared with the CRT display of the Mark IV. The tests showed that impedance matching improves the ultrasonic signal-to-noise ratio by approximately 8 decibels with 250 feet of cable, confiming the calculated results. A common 33-ohm 10% resistor, with a measured value of 30 ohms, produced the best results for the specific cable, transducer, and ultrasonic test unit being used in these experiments. The procedure for connecting a resistor in parallel with the transducer and waterproofing the connection is shown in Figure D-1.



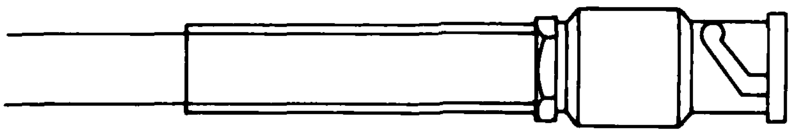
A. One lead of 33Ω resistor soldered to cable shield opposite lead soldered to no. 32 magnet wire



B. End of cable prepared for BNC plug in the normal manner. Magnet wire is run under the BNC nut, washer, gasket, and clamp looped around and soldered to the center conductor.



C. Center conductor pin soldered on and heat shrink tubing applied over magnet wire and dielectric.



D. Heat shrink over resistor. Drill out the BNC plug to accept the increased size of the dielectric with heat shrink tubing. Installed BNC as usual. Then waterproof the entire assembly.

Figure D-1. The procedure for connecting a resistor in parallel with the transducer and waterproofing the connection.

Appendix E

PROCEDURE FOR ULTRASONIC THICKNESS MEASUREMENT OF STEEL WATERFRONT STRUCTURES

1. PURPOSE

This procedure provides the requirements and information necessary to perform ultrasonic thickness measurements of the underwater portion of steel waterfront structures of Navy shore facilities.

2. SCOPE AND APPLICATION

Sheet piles and H-piles in waterfront structures within a nominal thickness range of 0.1 to 1.0 inch shall be measured.

Automated immersion, pulse-echo, straight beam longitudinal wave ultrasonic techniques shall be used in conjunction with focused transducers to conduct thickness measurements.

2.1 Applicable Documents

(1) Civil Engineering Laboratory (CEL) Technical Memorandum numbered 43-81-07 entitled "An Evaluation of Pulse Echo Ultrasonic Techniques for Underwater Inspection of Steel Waterfront Structures."

3. *PERSONNEL AND EQUIPMENT*

3.1 Personnel Certification and Training

Personnel performing ultrasonic examinations shall be certified to at least Level I in accordance with the guidelines of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A and Attachment A of this procedure. The personnel already certified to Level I shall receive one additional week of training culminating with a practical examination. The practical examination shall test the examiners proficiency using the required computer and/or ultrasonic equipment.

Personnel required for underwater work shall receive a minimum of one day of training using the actual equipment, as applicable.

3.2 Equipment

The examination system shall be comprised of the following equipment:

(1) Ultrasonic instrument with digital thickness meter
(2) Computer system
(3) Scanner bridge/surface milling adapter
(4) Search unit
(5) Calibration block
(6) Power system test circuit

3.2.1 Ultrasonic Instrument and Digital Thickness Meter

The following items are the minimum requirements for the ultrasonic instrument.

(1)	Power Requirements:	0.5 amperes at 115/120 volts AC 0.5 amperes at 24 volts DC
(2)	Power Consumption:	6 watts
(3)	Switched Testing Frequencies:	1.0, 2.25, 5.0, 10.0 MHz
(4)	Resolution over range of .1 to 1.0 inch:	0.030 inch with dual transducer 0.050 inch with single transducer
(5)	Temperature Operating Range:	-20° to 150°F
(6)	Calibrated dB Controls:	Coarse 0 to 90 dB in 10 dB steps; fine 0 to 15 dB in 1 dB steps
(7)	Receiver Gain:	110 dB minimum with receiver and video gain
(8)	Receiver Bandpass:	0.1 MHz to 25.0 MHz
(9)	Receiver Sensitivity:	At selected switched frequencies, an input signal of 10 microvolts RMS is clearly visible above base line noise
(10)	Pulse Repetition Frequency:	Low 100 and 500 pp; medium 1000 pps; high 3000 pps ± 25%
(11)	Maximum Pulser Voltage:	300 v into 500 ohms
(12)	Output Signal:	Analog thickness to voltage 0-5 Volts DC

The following items are the minimum requirements for the digital thickness meter.

(13)	Measurement Range:	0.010 to 19.99 inches
(14)	Blocking Gate Range:	0.020 inch of steel to greater than 10.0 inches of steel
(15)	Operating Temperature Range:	0° to 120° F
(16)	Output Signal:	Analog thickness to voltage 0-5 Volts DC

(17) Temperature Stability: 0.005% per degree centigrade

(18) Warm Up Time: One minute for full accuracy

3.2.2 Digital Voltmeter

The following items are the minimum requirements for the digital voltmeter.

(1) Capable of converting the thickness analog signal to a binary code

(2) IEEE-488 compatible

(3) Capable of 500 readings a second minimum

(4) Triggered internally and externally

(5) Accuracy of ±0.1 volt

An additional voltmeter will be required which shall be capable of converting 6 analog to binary readings per second.

3.2.3 Computer System

The following items are the minimum requirements for the computer system.

(1) 8-bit processor

(2) Alphanumeric and graphic display (300 by 400 dot minimum)

(3) Typewriter-type keyboard

(4) Mass storage - tape or disk

(5) IEEE-488 - 1978 interface

(6) RAM-based BASIC language with graphic support

(7) 32K RAM memory minimum

(8) Graphic's printer with dot-for-dot graphics copy

- 128 character USASCII character set, 132 columns
- 120 character/second minimum

(9) Digital clock incorporated in system or as a peripheral with IEE-488 interface

3.2.4 Scanner Bridge and Surface Milling Adapter

The following items are the minimum requirements for the scanner bridge.

(1) Linear scanner with manual control

(2) Accuracy of 0.020 inch

(3) Resolution of 0.010 inch

(4) Repeatability within 0.020 inch

(5) Maximum scan to at least 15 inches

(6) Used to attach scanner bridge to examination area
Four 300 pound pull magnets

The items following are the minimum requirements for the hydraulic surface milling adapter.

(1) Fit on the scanner bridge in the same location as the search unit

(2) Bayonet locking device for easy exchange with search unit

(3) Input of 4 GPM at 2000 PSI

(4) Output of 3000 rpm

(5) 4 flute 1/4-inch diameter end mill

(6) Vertical feed providing 0.010-inch increments in slot depth

3.2.5 Search Unit

The following items are the requirements for the ultrasonic search unit.

(1)	Frequency:	5.0 MHz
(2)	Focal Length:	2 inches
(3)	Diameter:	1/2 inch
(4)	Search Unit Cable:	Up to 200 foot waterproof with matched impedance
(5)	Type Search Unit:	Immersion

3.3.6 Calibration Block

The following are the minimum requirements for the step thickness calibration block.

(1)	Material:	Same basic material as examination area
(2)	Number of Steps:	4 minimum
(3)	Thickness of Steps:	One step 0.10 inch less than thinnest anticipated examination area, one step 0.10 inch greater than thickest examination area, and two intermediate steps when practical

3.2.7 Power System Test Circuit

Underwater ultrasonic test equipment supplied with 110 volts AC shall be tested as described in Appendix B to ensure diver safety.

3.2.8 Equipment List

The following is a list of equipment which was used during the development of this procedure.

(1) Sonic Mark IV Ultrasonic Flaw/Thickness Scope

(2) Model 220 Thickness Adapter

(3) Hewlett-Packard Digital Voltmeter HP-3437A

(4) Hewlett-Packard System Voltmeter HP-3455A

(5) IEEE-488 interface bus

(6) Plotter/printer with Tektronic 4052 desk top computer or Hewlett-Packard HP-85 desk top computer

(7) Digital clock 59309AHP-1 B H.P.

4. CALIBRATION METHOD

The complete ultrasonic thickness measurement system calibration shall be performed prior to commencing any thickness measurements.

4.1 Equipment Setup

The search unit shall be placed in the scanner bridge with a 1.0-inch standoff distance. A waterproof neoprene jacketed search unit cable shall be used to connect the search unit to the ultrasonic instrument. The ultrasonic instrument shall be linked to a digital thickness meter which will provide an external analog voltage proportional to the material thickness. The digital thickness meter shall have a digital voltmeter attached. The voltmeter will be capable of converting the thickness analog to a binary code and transfer it to a computer over an IEEE 488 interface bus. The computer system shall have a storage system, plotter and digital clock integrated in the system, so that the system can analyze, store, graph, and record the date and time of data received. Sketch 1 shows a block diagram of the data acquisition system.

4.2 Signal Characteristics

The ultrasonic signal with the cleanest sharpest leading edge shall be utilized during calibration and measurements to ensure accuracy. The signal shall be checked as follows:

(1) Obtain a back reflection of 80-90% full screen height (FSH) from the step thickness calibration block.

(2) Observe the signal's leading edge for facets (jaggedness) of sufficient amplitude to continuously trigger the time gate.

(3) Remove and replace the search unit several times to assure the signal characteristics remain similar.

(4) Utilize video, damping, reject, filters, half-cycle switches, as applicable, to obtain the signal with the cleanest, sharpest leading edge. These instrument settings shall be used for calibration and measurements.

4.3 Distance Calibration

The water path or stand off distance shall be 1.0 inch. The examiner shall ensure water bubbles are not on the search unit face during calibration and examination.

Signals from the entry surface and the initial pulse shall be out of the gated area of the ultrasonic instrument.

Obtain a signal from the thinnest and then the thickest step in the step thickness calibration block. Adjust the instrument controls while observing each of the two signals until a linear screen size is established. The screen distance shall be large enough to encompass the material thickness to be measured.

After the preliminary screen distance calibration with the data acquisition system set up as shown in Sketch 1, obtain a printout from the computer for each applicable step in the step thickness calibration block. A second order polynomial regression analysis shall be used to develop the computer calibration curve. Each step shall be measured within 0.002 inch or the instrument shall be recalibrated. The calibration printout from the computer shall be conducted with the instrument gain controls adjusted to the sensitivity required for the measurements to be conducted. A piece of material similar to the examination surface may be used to establish this nominal sensitivity.

A scanner positional verification shall be conducted during the initial calibration and at least every four hours of use. This check shall verify the search unit position with respect to the scanner framework. Place a reference mark on the scanner framework while positioned at 0 inches. Attach a pointer to the search unit or search unit holder so that the end of the pointer is as close as practical to the reference mark. Mark a reference point on the scanner framework at a whole inch interval. Drive the search unit to the appropriate whole inch position. Verify the position read out is 0.020 inch of the actual distance. Drive the search unit back to 0 inches and verify the pointer is aligned with the reference mark. Repeat this operation for additional reference points, if determined necessary to assure the scanner accuracy.

4.4 Calibration Verification

4.4.1 Sweep Range Verification

Sweep range calibration shall be verified on each step of the step thickness calibration block used to calibrate the instrument:

(1) At the start of a series of measurements

(2) At least every four hours

(3) With any substitution of the same type and length of search unit cable

(4) With any substitution of power source

(5) Whenever the calibration is in doubt

(6) At the finish of a series of measurements

4.4.2 Calibration Changes

Perform the following if the distance calibration has changed on the computer printout more than 0.003 inch:

(1) Void all measurements referring to the calibration in question and performed after the last valid calibration verification.

(2) Conduct a new calibration.

(3) Remeasure the areas for which measurements have been voided.

4.4.3 Recalibration

Substitution of any of the following shall be cause for recalibration:

(1) Search unit

(2) Search unit cable type or length

(3) Ultrasonic instrument

(4) Digital thickness meter

(5) Examination personnel

4.5 Calibration Data

Calibration data shall include, but not be limited to, the following:

(1) Serial number of the step thickness calibration block used

(2) Type and serial number of the ultrasonic instrument

(3) Type, size, beam angle, and serial number of the ultrasonic search unit

(4) Nominal search unit frequency

(5) Calibration curve

(6) Signature and ultrasonic certification level of the examiner conducting calibration

(7) Date calibrated

(8) Instrument settings

(9) Time of calibration and calibration verification(s)

(10) Cross section scan display of step thickness calibration block

5. EXAMINATION

A visual examination shall be conducted prior to taking any measurements. The general surface condition and areas of the greatest deterioration shall be noted.

Measurements shall be conducted at the following locations as a minimum:

(1) Tidal zone

(2) Mid-region of pile length

(3) Regions adjacent to sections of concrete cover

(4) Areas of deterioration as determined by the visual examination

Areas too severely pitted shall have a minimum 1/4-inch wide slot machined in the front surface of the examination area. The milling adapter is designed to fit into the bridge plate of the ultrasonic scanner in the same location as the search unit to assure the scan is made in the proper location. The process should involve alternately milling (.010-.020 increment) and ultrasonic scanning until at least 75% of the back wall can be identified or until 70 to 80 percent of the maximum pit depth is reached.

5.1 Measurement Data

Measurement data shall include, but not be limited to:

(1) Identification of component measured

(2) Location of measurements

(3) Cross section scan display

(4) Minimum and maximum thickness

(5) Average thickness

(6) Standard deviation

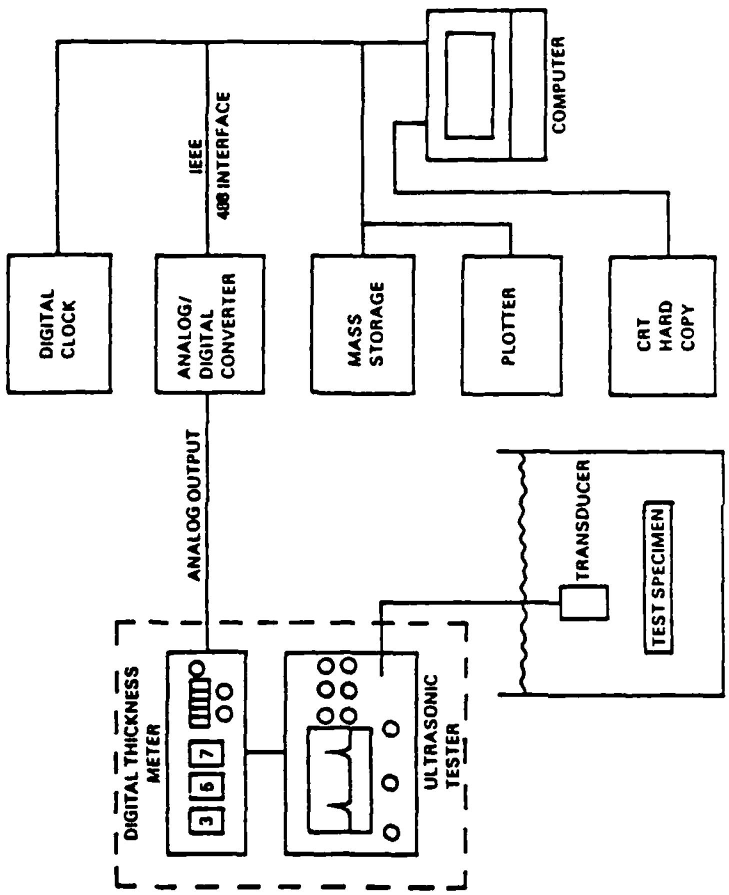
6. EVALUATION

A comparison shall be made between the thickness readings obtained during both previous and current measurements. Areas measured for the first time shall be compared to the nominal thicknesses to determine the degree of deterioration.

The thickness measurements taken in accordance with this procedure shall be evaluated by the Naval Civil Engineering Laboratory and the Engineer in charge of the inspection.

7. RECORDS

The cross sectional plots, calibration records, computer tapes or disks, and any other documentation shall be stored and available for future comparisons.



SCHEMATIC OF ULTRASONIC THICKNESS TEST SYSTEM

SKETCH 1

Attachment A

MINIMUM TRAINING AND EXPERIENCE LEVELS

	TRAINING (HOURS)	
	Ultrasonics	
	Level I	Level II
Completion with a passing grade of at least 2 years of engineering or science study at a university, college, or technical school	24	40
High school graduation, diploma or its equivalent	40	40
Grammar school graduation, or demonstrated proficiency or additional training	40	80
	WORK TIME EXPERIENCE (MONTHS)	
All educational levels as listed above	3	9

NOTES: For Level II certification, the experience shall consist of time at Level I. If a person is being qualified directly to Level II with no time at Level I, the required experience shall consist of the sum of the times required for Level I and Level II as a trainee and the hours of training required for Level I and Level II in total shall apply.

Appendix F

UNDERWATER ULTRASONIC SCANNING SYSTEM
DATA ACQUISITION AND ANALYSIS SOFTWARE

ULTRASONIC SCANNING AND DATA ANALYSIS PROGRAMS

The software developed to automate the data acquisition, storage, and analysis of ultrasonic thickness measurements consists of three programs:

1. Calibration

2. Scanning (data acquisiton)

3. Data print out and analysis

Each program was written in the Advanced BASIC programming language. The first two have been written for both the Hewlett-Packard HP85 and Tektronix 4052, while the data print out and analysis has been developed only for the Tektronix 4052 because of its greater computational speed.

TRANSDUCER CALIBRATION

The calibration (CAL) program provides the algorithms to calibrate the ultrasonic transducer and scanner position transducer. The ultrasonic transducer is calibrated by moving it across the surface of a calibration block with four steps ranging from 0.200 inch to 0.500 inch in 0.100-inch increments. During a 10-second period the computer acquires 1,000 thickness readings of the four steps. The individual thickness readings are then sorted into frequency of occurrence modes and checked to assure that only four modes, corresponding to steps in the calibration bar, have been identified. The mean and standard deviation of each mode are calculated, and a second-order polynomial regression analysis is performed on the data to obtain constants for the calibration equation used to calculate material thickness in the scanning program. The calibration equation is:

$$y = B_0 + B_1x + B_2x^2$$

where

y = calculated material thickness

x = thickness analog voltage

and the constants B_0, B_1, and B_2 are calculated from the following algorithm. For the generalized equation

$$y = \sum_{i=0}^{k} B_i x^i = B_0 + B_1 x^1 + B_2 x^2 \ldots B_k x^k$$

the constants B_i are obtained from the matrix solution

$$[B] = [A]^{-1} L [C]^T$$

where

$$A_{ij} = n \sum x^{(i+j)} - \sum x^i - \sum x^j$$

$$C_{ij} = \sum x^j y - \sum x^j \sum y$$

and

$$B_0 = \frac{\sum Y - \sum \left(B_i \sum x_i \right)}{n}$$

The axial position of the transducer in the scanner is then calibrated by comparing the voltage reading from a position potentiometer to the measured distance of travel. The slope and axis intercept are calculated to equate voltage readings to actual transducer positions.

A calibration curve is generated and displayed on the computer CRT to provide a quick visual check on the accuracy and linearity of the calibration.

The calibration routines are contained in subprograms that are called by the operator when needed using "user definable keys" located on the computer keyboard. With the "user keys" the operator can interrupt program flow, select calibration routines, and restart a routine by pressing the appropriate key.

When the computer and operator agree that the calibration is valid, the data are stored on mass storage for later recall along with operator input information pertaining to transducer model, operating frequency, and standoff distance.

The program logic flow diagram is shown in Figure F-1, and the program listing is shown in Figure F-2.

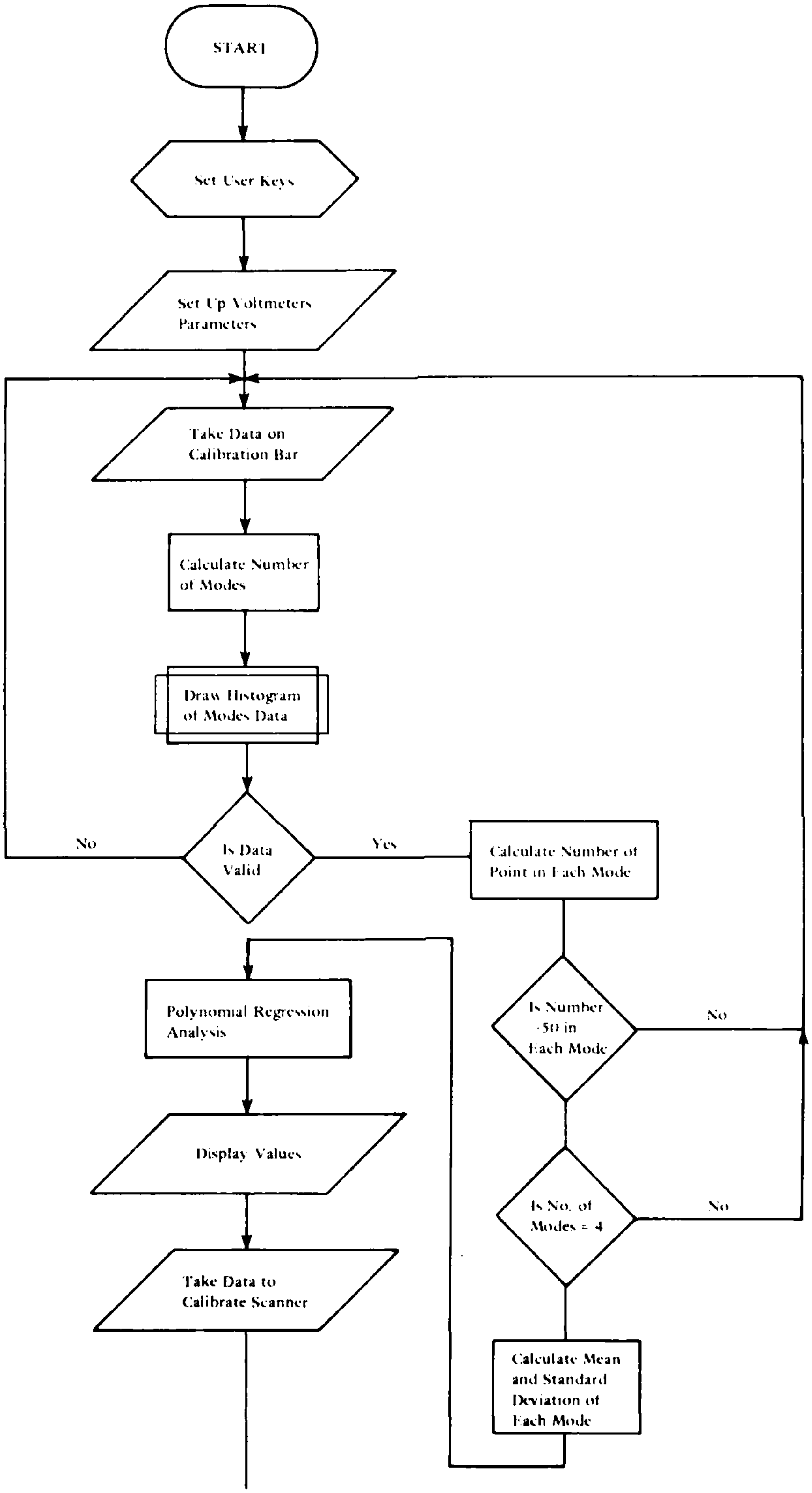


Figure F-1. Calibration program logic flow chart.

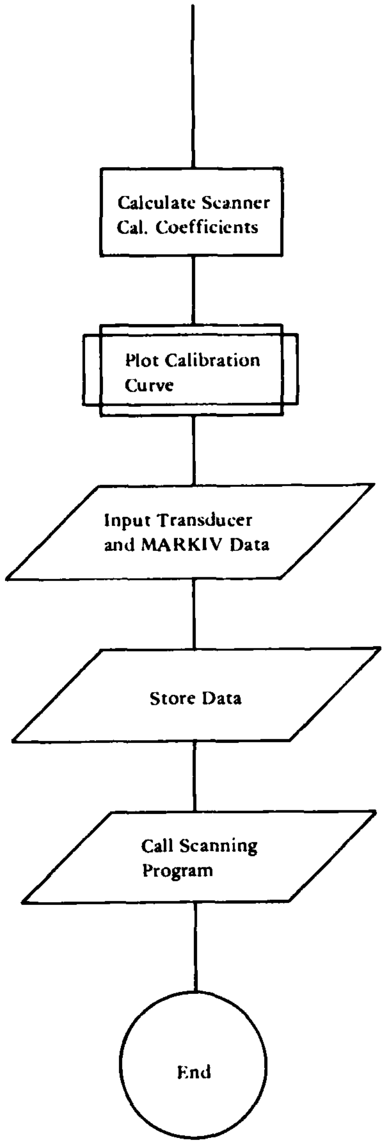


Figure F-1. Continued

```
10 ! TRANSDUCER CALIBRATION PROGRAM FOR DISC - CATALOG NAME "CAL"
20 OPTION BASE 1
30 ON KEY# 1,"CAL-T" GOTO 560
40 ON KEY# 2,"PLOT" GOSUB 2470
50 ON KEY# 3,"CAL-S" GOSUB 2590
60 ON KEY# 4,"T=0" GOTO 560
70 DIM T$[32],F$[32],E$[32],S$[32]
80 DIM V(1000),T(550),Y$[1],X1(9),Y(4),T1(9),N1(9),X(4),S9(9),E1(9),D1$[
7010]
90 DIM A(2,2),C(1,2),D(4),E(4),F(4),G(4),L(4),A1(2,2),B(2,1)
100 K=2
110 N=4
120 MAT V=(0)
130 DIM C1(2,1),Q(4),R(1,1),R2(1,1),S(1,1)
140 MAT X=(0)
150 MAT Y=(0)
160 MAT T=(0)
170 S1=0
180 S2=0
190 ! PRINT TITLE
200 CLEAR
210 IMAGE "********************************"
220 IMAGE "*",4X,"TRANSDUCER CALIBRATION",3X,"*"
230 DISP USING 210
240 DISP USING 220
250 DISP USING 210
260 ! READ DATE FROM 59309A
270 ENTER 726 ; J$
280 T9=VAL(J$[9,15])
290 IF T9>=12 THEN 330
300 !
310 DISP USING "1/,10X,K" ; "GOOD MORNING" @ DISP
320 GOTO 340
330 DISP USING "1/,9X,K" ; "GOOD AFTERNOON" @ DISP
340 DISP "THE DATE IS:";J$[1,8]&"82"
350 ABORTIO 7
360 DISP
370 DISP "PLEASE ENTER THE FOLLOWING DATA"
380 DISP USING 210
390 DISP
400 !
410 ! ENTER TRANSDUCER DATA
420 DISP "TRANSDUCER ID CODE";
430 INPUT T$
440 DISP "FREQUENCY (MHZ):";
450 INPUT F$
460 DISP "ELEMENT DIAMETER (INCHES):";
470 INPUT E$
480 DISP "STANDOFF DISTANCE (INCHES):";
490 INPUT S$
500 DISP
510 DISP USING 210
520 ! PROGRAM 3457 FOR BURST READINGS
530 ! INITIATE CALIBRATION
540 CLEAR @ DISP "SELECT OPTION" @ KEY LABEL
550 GOTO 550
560 DISP "TAKING DATA" @ BEEP
570 ! PROGRAM 3457 FOR BURST READINGS
580 OUTPUT 724 ;"F1T1R2N1000SE0SD0.010S"
```

Figure F-2. Transducer calibration program.

```
590 IOBUFFER D1$
600 TRANSFER 724 TO D1$ FHS : EOI
610 OUTPUT 724 USING "2A" ; "T3"
620 ABORTIO 7
630 DISP "PROCESSING DATA" @ BEEP
640 O6=LEN(D1$)-1
650 O5=0
660 FOR O4=1 TO O6 STEP 7
670 O5=O5+1
680 V(O5)=VAL(D1$[O4,O4+5])*1000
690 IF V(O5)>550 OR V(O5)<1 THEN 710
700 T(V(O5))=T(V(O5))+1
710 NEXT O4
720 ! CALCULATE VALUES FOR HISTOGRAM
730 ! DRAW HISTOGRAM AXIS
740 GCLEAR
750 SCALE -75,550,-25,300
760 XAXIS 0,50,0,550
770 YAXIS 0,50,0,300
780 ! LABEL AXIS
790 LDIR 0
800 FOR I=0 TO 500 STEP 100
810 MOVE I-20,-20
820 LABEL I*.001
830 NEXT I
840 !
850 FOR I=50 TO 300 STEP 100
860 MOVE -75,I-5
870 LABEL I
880 NEXT I
890 MOVE 0,50 @ DRAW 550,50
900 ! DRAW HISTOGRAM
910 MOVE 0,0
920 FOR I=1 TO 550
930 DRAW I,T(I)
940 NEXT I
950 MOVE 100,250
960 LABEL "DATA VALID [Y/N]:"
970 INPUT Y$
980 IF Y$="" THEN 1000
990 IF Y$="Y" THEN 1020
1000 GCLEAR
1010 GOTO 520
1020 Z=0
1030 MAT T1=(0)
1040 MAT N1=(0)
1050 J=1
1060 ! CALIBRATION THICKNESS
1070 Y(1)=.2
1080 Y(2)=.3
1090 Y(3)=.4
1100 Y(4)=.5
1110 ! CALCULATE DATA MODES
1120 Z1=0
1130 MAT S9=(0)
1140 MAT E1=(0)
1150 FOR I=1 TO 550
1160 IF T(I)=0 THEN 1250
1170 IF Z1=1 THEN 1200
1180 S9(J)=I
```

Figure F-2. Continued

```
1190 Z1=1
1200 T1(J)=T1(J)+.001*I*T(I)
1210 N1(J)=N1(J)+T(I)
1220 E1(J)=I
1230 Z=0
1240 GOTO 1270
1250 Z=Z+1
1260 IF Z>5 THEN 1370
1270 NEXT I
1280 ! CHECK # OF MODES
1290 IF J=5 THEN 1470
1300 MOVE 280,250
1310 DISP "DATA INVALID" @ BEEP
1320 MOVE 280,220
1330 DISP "NUMBER OF MODES=";J-1
1340 WAIT 3000
1350 GOTO 520
1360 ! CHECK # OF DATA POINTS IN MODE
1370 IF N1(J)>50 THEN 1430
1380 Z1=0
1390 N1(J)=0
1400 T1(J)=0
1410 GOTO 1230
1420 ! CALC. MEAN VALUE OF MODE
1430 X1(J)=T1(J)/N1(J)
1440 Z1=0
1450 J=J+1
1460 GOTO 1270
1470 ! POLYNOMIAL REGRESSION ANALYSIS
1480 FOR I=1 TO 4
1490 X(I)=X1(I)
1500 NEXT I
1510 CLEAR
1520 MAT D=X.X
1530 MAT E=D.X
1540 MAT F=E.X
1550 MAT G=X.Y
1560 MAT L=D.Y
1570 A(1,1)=N*SUM(D)-SUM(X)*SUM(X)
1580 A(1,2)=N*SUM(E)-SUM(D)*SUM(X)
1590 A(2,1)=A(1,2)
1600 A(2,2)=N*SUM(F)-SUM(D)*SUM(D)
1610 C(1,1)=N*SUM(G)-SUM(X)*SUM(Y)
1620 C(1,2)=N*SUM(L)-SUM(D)*SUM(Y)
1630 MAT C1=TRN(C)
1640 MAT B=SYS(A,C1)
1650 DISP USING "4A,2X,3A,4X,3A,2X,4A,2X,7A" ; "MODE";"MIN";"MAX";"MEAN"
;"READING"
1660 !
1670 FOR I=1 TO 4
1680 DISP USING 1700 ; I,S9(I)*.001,E1(I)*.001,X(I),N1(I)
1690 NEXT I
1700 IMAGE 2X,D,2X,D.3D,2X,D.3D,X,D.3D,3X,K
1710 DISP "THE REGRESSION COEFFICIENS ARE:"
1720 !
1730 Y1=0
1740 MAT D=X.X
1750 Y1=B(1,1)*SUM(X)+B(2,1)*SUM(D)
1760 T9=SUM(Y)
1770 Y0=(T9-Y1)/N
```

Figure F-2. Continued

```
1780 MAT R=C*B
1790 MAT Q=Y.Y
1800 U=SUM(Q)
1810 S=N*U-T9^2
1820 MAT R2=(1/S)*R
1830 R1=SQR(ABS(R2(1,1)))
1840 DISP Y0
1850 FOR J=1 TO K
1860 DISP USING 1960 ; B(J,1)
1870 NEXT J
1880 B1=B(1,1)
1890 B2=B(2,1)
1900 DISP "THE SAMPLE CORRELATION COEFFICIENT IS:"
1910 DISP USING 1960 ; R1
1920 DISP "DO YOU WANT TO CALIBRATE THE SCANNER [Y/N]:"
1930 INPUT Y$
1940 IF Y$="N" THEN 1990
1950 GOSUB 2590
1960 IMAGE 5D.4D
1970 IMAGE S5D.4D,3A,5D,K
1980 !
1990 DISP
2000 DISP "DO YOU WANT A PRINTOUT OF THE CALIBRATION CURVE? [Y/N]";
2010 !
2020 INPUT Y$
2030 IF Y$="Y" THEN 2050
2040 IF Y$="N" THEN 2390
2050 ! CALIBRATION CURVE PLOT SUBPROGRAM
2060 GCLEAR
2070 LDIR 0
2080 SCALE -.1,.65,-.1,.7
2090 XAXIS 0,.1,0,.6
2100 YAXIS 0,.1,0,.6
2110 MOVE .05,.65
2120 LABEL "TRANSDUCER CALIBRATION"
2130 MOVE .2,-.1
2140 LABEL "VOLTAGE"
2150 MOVE -.05,.2
2160 LDIR 90
2170 LABEL "THICKNESS"
2180 LDIR 0
2190 FOR I=0 TO .6 STEP .1
2200 MOVE I-.035,-.045
2210 LABEL I
2220 NEXT I
2230 FOR I=0 TO .6 STEP .1
2240 MOVE -.07,I-.01
2250 LABEL I
2260 NEXT I
2270 MOVE 0,0
2280 FOR Z=0 TO .6 STEP .01
2290 DRAW Z,Y0+B(1,1)*Z+B(2,1)*Z^2
2300 NEXT Z
2310 FOR I=1 TO N
2320 MOVE X(I),Y(I)
2330 IDRAW .005,0
2340 IDRAW -.01,0
2350 IMOVE .005,.008
2360 IDRAW 0,-.016
2370 NEXT I
```

Figure F-2. Continued

```
2380 GSTORE "CAL CU.DRIVE0"
2390 ASSIGN# 1 TO "DATA 1.DRIVE0"
2400 PRINT# 1 ; Y0,B1,B2,S1,S2,T$,F$,E$,S$
2410 ASSIGN# 1 TO *
2420 CLEAR
2430 DISP "PRESS [END LINE] FOR SCANNING PROGRAM"
2440 INPUT Y$
2450 CHAIN "SCAN.DRIVE0"
2460 END
2470 ! SUBROUTINE TO PLOT VOLTAGE DATA
2480 SCALE 0,1000,0,1000
2490 XAXIS 100,200
2500 YAXIS 100,200
2510 FOR I=1 TO 1000
2520 MOVE I,V(I)
2530 DRAW I,V(I)
2540 NEXT I
2550 MOVE 250,950
2560 DISP "KEY [END LINE] TO CONTINUE PROGRAM"
2570 INPUT Y$
2580 RETURN
2590 ! SUBROUTINE TO CALIBRATE SCANNER
2600 OUTPUT 722 ;"F1T3A1M3H0R7D0"
2610 DISP "ENTER POSITION OF SCANNER HEAD:";
2620 INPUT S5
2630 DISP "KEY [END LINE] TO TAKE VOLTAGE READING";
2640 INPUT Y$
2650 TRIGGER 722
2660 WAIT 300
2670 ENTER 722 ; V5
2680 DISP "MOVE SCANNER HEAD AND ENTER NEW POSITION:";
2690 INPUT S6
2700 DISP "KEY [END LINE] TO TAKE VOLTAGE READING";
2710 INPUT Y$
2720 TRIGGER 722
2730 WAIT 300
2740 ENTER 722 ; V6
2750 S2=(S6-S5)/(V6-V5)
2760 S1=S5-S2*V5
2770 DISP "THE CALIBRATION COEFFICIENTS ARE:"
2780 DISP S1
2790 DISP S2
2800 RETURN
```

Figure F-2. Continued

SCANNING THICKNESS MEASUREMENTS

The scanning (SCAN) data acquisition program is operator controlled by "user definable keys" to start, stop, print previous data, restart, and store data on disk or magnetic tape.

At the start of the SCAN program the calibration equation coefficients are acquired from a temporary data file and the data acquisition system voltmeters are set under program control. When the "start scan" key is pressed, voltage data from the ultrasonic and scanner position transducer are obtained and substituted into the calibration transducer to produce estimates of the material thickness and location of the measurement position.

SCAN graphically displays, in real-time, a thickness versus length (position) point slot as the transducer scans the specimen. The thickness reading is averaged with each successive pass at each point a reading is taken. The thickness readings and position readings are then stored in two 1,500-element, one-dimensional arrays. Each element of the array represents a 0.01-inch-wide cell along the surface of the structure being scanned. The maximum of 1,500 was selected to provide enough points for statistical analysis and yet not overflow memory of a 32K-byte computer.

At the completion of the scan and cross-sectional print out, the operator is prompted to enter information about the inspection and site parameters. These data along with the thickness measurements are then stored on magnetic tape or floppy disk for later analysis.

The program logic flow diagram is shown in Figure F-3, and the program listing is shown in Figure F-4.

DATA PRINT OUT AND ANALYSIS

The data print out and analysis programs consist of a data print out program and a statistic and probability analysis program linked to and accessible only through the data print out program.

The data to be analyzed are retrieved from mass storage, and test information and calibration coefficients are displayed on the computer CRT. The scanning data are then plotted as originally taken. Elimination of unwanted data by editing, filtering, and replotting of data is carried out by the operator using the user definable keys. Once the data are edited, the operator calls up the statistics and probability analysis program. The statistics routine prints out: (1) area scanned, (2) mean thickness, (3) standard deviation, (4) coefficient of variation, (5) number of readings, and (6) filtered thickness. The probability routine produces a distribution histogram of the thickness versus the number of readings at that thickness.

The data print out and analysis program flow is controlled by the operator via user definable keys; editing is entirely operator controlled.

The program logic flow diagram is shown in Figure F-5, and the program listing is shown in Figure F-6.

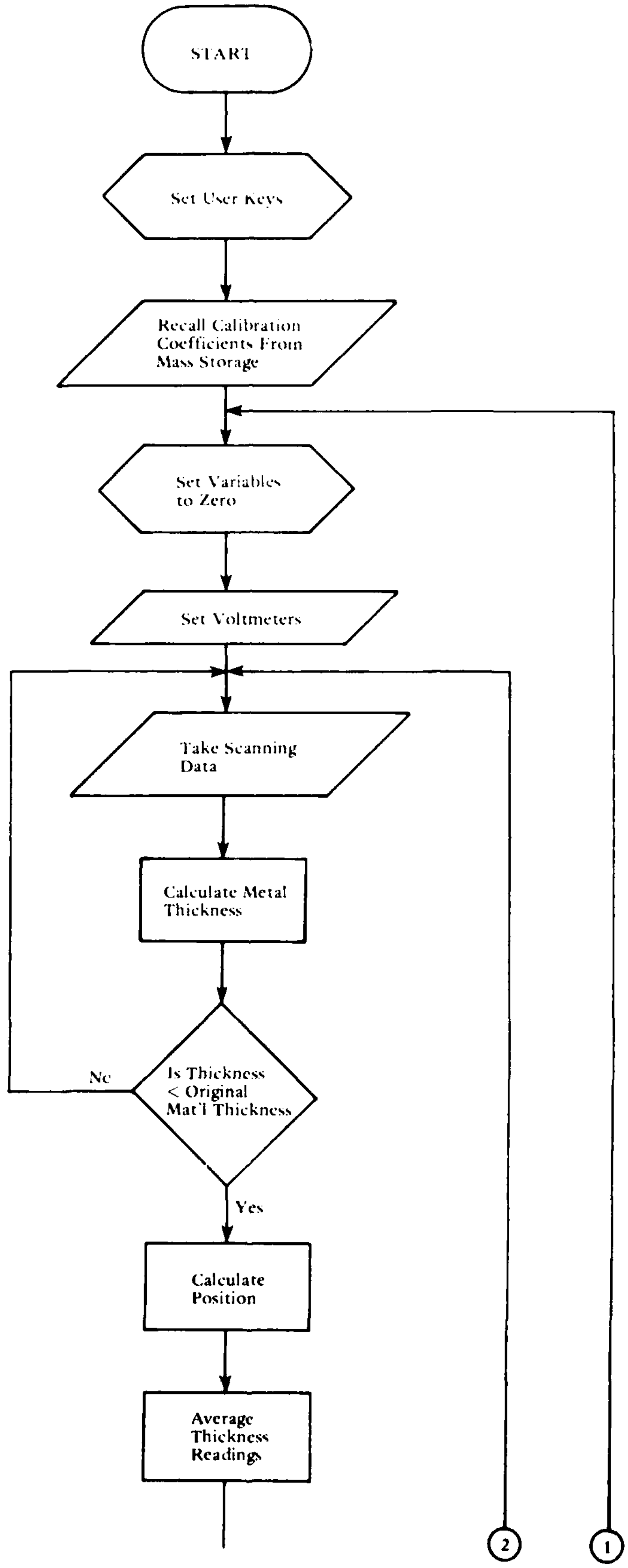


Figure F-3. Scan program logic flow chart.

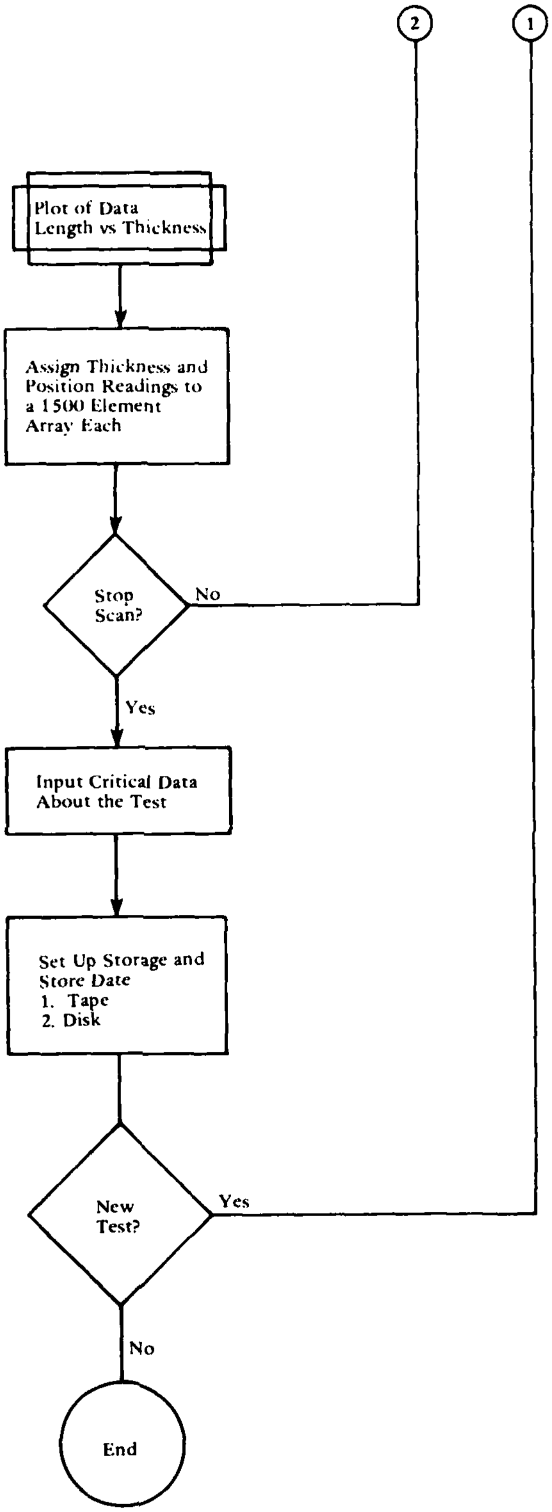


Figure F-3. Continued.

```
10 ! ULTRASONIC SCANNING FOR DISC - CATALOG NAME "SCAN"
30 RESET 7 @ DIM T$[32],F$[32],E$[32],S$[32]
40 ASSIGN# 1 TO "DATA 1.DRIVEØ"
50 READ# 1 ; YØ,B1,B2,S1,S2,T$,F$,E$,S$
60 ASSIGN# 1 TO *
70 ON KEY# 1,"SCAN" GOTO 310
80 ON KEY# 2,"STOP" GOTO 280
90 ON KEY# 3,"ERASE" GOTO 310
100 ON KEY# 4,"LAST" GOSUB 540
110 ON KEY# 5,"DATA>TK" GOTO 630
120 ON KEY# 6,"DATA>D" GOTO 1300
130 ON KEY# 7,"DATA>85" GOTO 1520
140 CLEAR @ GCLEAR
150 DIM T(1500),P(1500)
160 DIM T2(1),N$[72],L$[54],C$[54],O$[54],W$[6],A$[8],B$[8],Q$[8],G$[32]
,R$[32],D$[32]
170 IMAGE "*********************************"
180 IMAGE "*",5X,"ULTRASONIC SCANNING",6X,"*"
190 DISP USING 170
200 DISP USING 180
210 DISP USING 170
220 ENTER 726 ; K$
230 A$=K$[3,8]&"82"
240 B$=K$[9,16]
250 RESET 7
260 DISP @ DISP @ DISP "DATE OF TEST-";A$
270 DISP @ DISP "TIME OF TEST-";B$ @ DISP @ DISP
280 DISP @ DISP "PRESS KEY 'K1' TO START SCAN" @ KEY LABEL
290 GOTO 290
300 ! ROUTINE TO AQUIRE SCANNING DATA
310 GOSUB 490
315 ON ERROR GOSUB 1720
320 MAT T=ZER@ MAT P=ZER
340 OUTPUT 724 ;"DØS N1S R3T3F1"
350 OUTPUT 722 ;"F1HØT2A1M3R7DØ"
360 TRIGGER 724
365 ON ERROR GOSUB 1720
370 ENTER 724 ; V1
380 T1=YØ+B1*V1+B2*V1^2
390 IF T1<Ø OR T1>1 THEN 360
400 ENTER 722 ; V2
410 P1=S1+S2*V2
420 I=INT(P1*100)
430 P(I)=P(I)+1
440 T(I)=T(I)+T1
450 T1=T(I)/P(I)
460 MOVE P1,T1 @ DRAW P1,T1
465 OFF ERROR
480 GOTO 360
490 ! SET UP SCANNING DISPLAY
500 SCALE Ø,16,Ø,1
510 XAXIS Ø,.5 @ YAXIS Ø,.1
520 GSTORE "SCANDIS.DRIVEØ" @ RETURN
540 ! ROUTINE TO DRAW PREVIOUS DATA
560 GCLEAR @ GLOAD "SCANDIS.DRIVEØ"
570 FOR J=1 TO 1500
580 IF T(J)=Ø THEN 610
590 MOVE J*.01+.ØØ5,T(J)/P(J)
600 DRAW J*.01+.ØØ5,T(J)/P(J)
```

Figure F-4. Ultrasonic scanning program.

```
610 NEXT J
620 GOTO 360
630 ! STORE DATA ON TEK 4924 TAPRE DRIVE
640 ENTER 726 ; K$
650 Q$=K$[9,16] @ RESET 7
670 GCLEAR @ CLEAR @ DISP "SCAN COMPLETED" @ DISP
680 GOSUB 700
690 GOTO 810
700 DISP "PLEASE ENTER THE FOLLOWING DATA" @ DISP
710 DISP "GAIN SETTING(dB):";@ INPUT G$
720 DISP "VIDEO REJECT:";@ INPUT R$
730 DISP "DAMPING:";@ INPUT D$
740 DISP "DATA TAPE ID. NO:";@ INPUT T2
750 DISP "FILE NAME (72 CHARS.)" @ INPUT N$
760 DISP "TEST LOCATION (54 CHARS.)" @ INPUT L$
770 DISP "TEST SPECIMEN (54 CHARS.)" @ INPUT C$
780 DISP "OPERATOR(S) (54 CHARS.)" @ INPUT O$
790 DISP "WATER DEPTH (6 CHARS.)" @ INPUT W$
800 RETURN
810 DISP "ENTER FILE # TO STORE DATA" @ INPUT Y
820 DISP "PRESS 'CONT' TO BEGIN DATA TRANSFER" @ PAUSE
830 ENTER 726 ; K$
840 Q1$=K$[9,16]
850 DISP "START TRANSFER ";Q1$
860 SEND 7 ; UNL LISTEN 25 SCG 27 MTA
870 OUTPUT 7 ;Y
880 SEND 7 ; UNL LISTEN 25 SCG 28 MTA
890 OUTPUT 7 ;1,71000
900 SEND 7 ; UNL LISTEN 25 SCG 27 MTA
910 OUTPUT 7 ;Y
920 SEND 7 ; UNL LISTEN 25 SCG 12 MTA
930 OUTPUT 7 ;N$
940 OUTPUT 7 ;Y0
950 OUTPUT 7 ;B1
960 OUTPUT 7 ;B2
970 OUTPUT 7 ;S1
980 OUTPUT 7 ;S2
990 OUTPUT 7 ;T2
1000 OUTPUT 7 ;T$
1010 OUTPUT 7 ;F$
1020 OUTPUT 7 ;E$
1030 OUTPUT 7 ;S$
1040 OUTPUT 7 ;G$
1050 OUTPUT 7 ;R$
1060 OUTPUT 7 ;D$
1070 OUTPUT 7 ;A$
1080 OUTPUT 7 ;B$
1090 OUTPUT 7 ;L$
1100 OUTPUT 7 ;C$
1110 OUTPUT 7 ;O$
1120 OUTPUT 7 ;W$
1130 OUTPUT 7 ;Q$
1140 FOR I=1 TO 1500
1150 OUTPUT 7 ;T(I)
1160 NEXT I
1170 FOR I=1 TO 1500
1180 OUTPUT 7 ;F(I)
1190 NEXT I
1200 SEND 7 ; UNL LISTEN 25 SCG 2 MTA
1210 RESUME 7
```

Figure F-4. Continued.

```
1220 ENTER 726 ; K$
1230 Q1$=K$[9,16]
1240 DISP "TRANSFER COMPLETE ";Q1$
1250 FOR I=1 TO 100
1260 BEEP I*RND+1,50
1270 NEXT I
1280 ABORTIO 7
1290 GOTO 290
1300 ! STORE DATA ON DISK
1310 MASS STORAGE IS ".DRIVE1"
1320 GCLEAR @ CLEAR @ DISP "SCAN COMPLETED" @ DISP
1330 GOSUB 700
1340 DISP "ENTER NAME OF DATA FILE (10 CHAR. MAX)" @ INPUT Z$
1350 DISP "PRESS 'CONT' TO BEGIN DATA TRANSFER " @ PAUSE
1360 !
1370 ENTER 726 ; K$
1380 Q$=K$[9,16]
1390 DISP "START TRANSFER";Q$
1400 CREATE Z$,1,27968
1410 ASSIGN# 1 TO Z$
1420 PRINT# 1 ; N$,Y0,B1,B2,S1,S2,T2,T$,F$,E$,S$,G$,R$,D$,A$,B$,L$,C$,O$
,W$,Q$,T(),P()
1430 ASSIGN# 1 TO *
1440 ENTER 726 ; K$
1450 Q$=K$[9,16]
1460 DISP "DATA TRANSFERRED";Q$
1470 FOR I=1 TO 100
1480 BEEP I*RND+1,50
1490 NEXT I
1500 ABORTIO 7
1510 GOTO 290
1520 ! STORE DATA ON HP TAPE
1530 MASS STORAGE IS ":T"
1540 GCLEAR @ CLEAR @ DISP "SCAN COMPLETED" @ DISP
1550 GOSUB 700
1560 DISP "ENTER NAME OF DATA FILE (6 CHAR.MAX)"
1570 INPUT Z$
1575 DISP "PRESS 'CONT'TO BEGIN DATA TRANSFER" @ PAUSE
1580 ENTER 726 ; K$
1590 Q$=K$[9,16]
1600 DISP "START TRANSFER ";Q$
1610 CREATE Z$,1,27968
1620 ASSIGN# 1 TO Z$
1630 PRINT# 1 ; N$,Y0,B1,B2,S1,S2,T2,T$,F$,E$,S$,G$,R$,D$,A$,B$,L$,C$,O$
,W$,Q$,T(),P()
1640 ASSIGN# 1 TO *
1650 ENTER 726 ; K$
1660 Q$=K$[9,16]
1670 DISP "DATA TRANSFERRED ";Q$
1680 FOR I=1 TO 100
1690 BEEP I*RND+1,50
1700 NEXT I
1710 GOTO 290
1720 OFF ERROR
1730 DISP "ERRN=";ERRN;"ERRL=";ERRL;"ERROM=";ERROM
1740 DISP "CORRECT CONDITION AND KEY 'CONT'"
1750 PAUSE
1760 RETURN
```

Figure F-4. Continued.

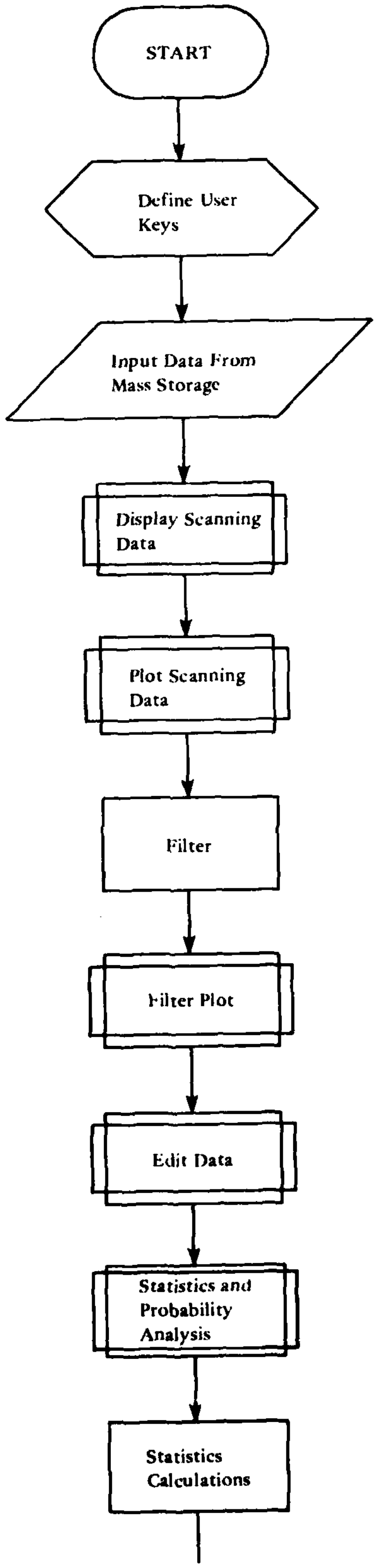


Figure F-5. Data printout and analysis program logic flow chart.

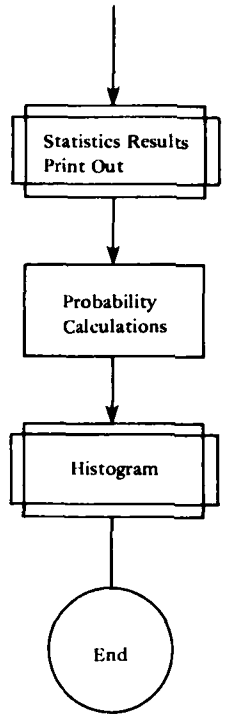


Figure F-5. Continued.

```
1 REM:FILE-#14---------------------- DATA PRINT OUT WITH PLOTTER OPTION
2 GO TO 100
4 GO TO 300
8 MOVE 0,0
9 PRINT @32,18:5
10 PRINT @32,24:"|";
11 GO TO 10
12 GO TO 1120
16 FIND 15
17 CALL "LINK";110
20 FIND 15
21 CALL "LINK";5000
24 RMOVE 0,0.005
25 RETURN
28 RMOVE 0,-0.005
29 RETURN
32 RMOVE -0.075,0
33 RETURN
36 RMOVE 0.075,0
37 RETURN
40 GO TO 260
44 GO TO 1300
64 GIN G1,M2
65 MOVE 0,M2
66 DRAW 15,M2
67 RETURN
68 GIN G1,M1
69 MOVE 0,M1
70 DRAW 15,M1
71 RETURN
72 GIN M3,G2
73 MOVE M3,0
74 DRAW M3,1
75 RETURN
76 GIN M4,G2
77 MOVE M4,0
78 DRAW M4,1
79 RETURN
100 INIT
110 SET KEY
120 PAGE
130 PRINT USING 140:
140 IMAGE 18X,36("*")
150 PRINT USING 160:"********  DATA PRINT OUT  ********"
160 IMAGE 19X,FA
170 PRINT USING 140:
180 PRINT "JJJENTER FILE # : ";
190 INPUT Y
200 FIND @2:Y
210 READ @2:N$,Y0,B1,B2,S1,S2,T1,T$,F$,E$,S$,G$,R$,D$,A$,B$,L$
220 READ @2:C$,O$,W$,Q$
230 DIM T(1500),P(1500)
240 READ @2:T
250 READ @2:P
260 M1=0
270 M2=1
280 M3=1.0E-3
290 M4=15
300 REM------------------------------------------------------PLOT
310 PAGE
```

Figure F-6. Data printout and analysis program.

```
320 PRINT "DO YOU WANT TO USE A PLOTTER? (Y OR N)";
330 INPUT J$
340 IF J$="Y" THEN 370
350 A1=32
360 GO TO 490
370 PRINT "JARE YOU USING THE TEKTRONIX 4662 OR HEWLETT-PACKARD 7225A ?"
380 PRINT "ENTER (T) FOR TEKTRONIX"
390 PRINT "ENTER (H) FOR HEWLETT-PACKARD"
400 INPUT J$
410 IF J$="T" THEN 440
420 IF J$="H" THEN 1900
430 GO TO 380
440 PAGE
450 PRINT "INSURE THAT PLOTTER IS SET UP AND KEY RETURN "
460 INPUT J$
470 PRINT "INPUT THE ADDRESS OF THE PLOTTER !! ";
480 INPUT A1
490 PAGE
500 HOME @A1:
510 WINDOW 0,15,0,1
520 VIEWPORT 10,120,10,90
530 PRINT @A1:"TEST SPECIMEN - ";
540 GIN @A1:X1,Y1
550 MOVE @A1:13,Y1
560 PRINT @A1:"DATA TAPE # ";T1
570 PRINT @A1:C$;
580 GIN @A1:X1,Y1
590 MOVE @A1:13,Y1
600 PRINT @A1:"FILE # ";Y
610 AXIS @A1:1,0.1
620 FOR I=1 TO 1500
630    IF T(I)=0 THEN 660
640    MOVE @A1:I*0.01+0.005,T(I)/P(I)
650    DRAW @A1:I*0.01+0.005,T(I)/P(I)
660 NEXT I
670 MOVE @A1:0,0
680 FOR I=0 TO 1 STEP 0.2
690    MOVE @A1:0,I
700    PRINT @A1:"HHHH";I;
710 NEXT I
720 MOVE @A1:0,0
730 FOR I=0 TO 15 STEP 2
740    MOVE @A1:I,0
750    PRINT @A1:"J";I
760 NEXT I
770 MOVE @A1:-1.1,0.83
780 V$=" SPECIMEN THICKNESS"
790 FOR I=1 TO LEN(V$)
800    X$=SEG(V$,I,1)
810    PRINT @A1:X$
820 NEXT I
830 MOVE @A1:6,0
840 PRINT @A1:"JJJSPECIMEN LENGTH";
850 MOVE @A1:0,M1
860 GOSUB 880
870 GO TO 930
880 FOR I=0 TO M3 STEP 0.4
890    RDRAW @A1:0.2,0
900    RMOVE @A1:0.2,0
910 NEXT I
```

Figure F-6. Continued.

```
920 RETURN
930 MOVE @A1:M3,0
940 GOSUB 960
950 GO TO 1010
960 FOR I=0 TO M1 STEP 0.026
970     RDRAW @A1:0,0.013
980     RMOVE @A1:0,0.013
990 NEXT I
1000 RETURN
1010 MOVE @A1:M4,0
1020 GOSUB 960
1030 MOVE @A1:0,M2
1040 GOSUB 880
1050 IF A1<>32 AND M4=15 THEN 1110
1060 MOVE @A1:M3,M1
1070 DRAW @A1:M4,M1
1080 DRAW @A1:M4,M2
1090 DRAW @A1:M3,M2
1100 DRAW @A1:M3,M1
1110 WAIT
1120 REM:-----------------------------------------------------------FILTER
1130 PAGE
1140 PRINT @32,18:0
1150 IF M1>M2 OR M3>M4 THEN 1270
1160 PRINT "PROCESSING DATAGGGG"
1170 FOR I=1 TO 1500
1180     IF P(I)=0 THEN 1240
1190     IF T(I)/P(I)>M2 OR T(I)/P(I)<M1 THEN 1220
1200     IF I<M3*100 OR I>M4*100 THEN 1220
1210     GO TO 1240
1220     T(I)=0
1230     P(I)=0
1240 NEXT I
1250 PRINT "DATA PROCESSING COMPLETEGGGG"
1260 WAIT
1270 PRINT "BOUNDARIES IMPROPERLY SPECIFIEDGGGGG"
1280 GO TO 320
1290 END
1300 REM:------------------------------------------------------FILTER PLOT
1310 PAGE
1320 PRINT "DO YOU WISH TO USE THE PLOTTER FOR THE FILTER PLOT ?"
1330 INPUT J$
1340 IF J$="Y" THEN 1370
1350 A1=32
1360 GO TO 1390
1370 PRINT "INPUT ADDRESS OF THE PLOTTER ";
1380 INPUT A1
1390 PAGE
1400 HOME @A1:
1410 WINDOW 0,15,0,1
1420 VIEWPORT 10,120,10,90
1430 PRINT @A1:"TEST SPECIMEN - ";
1440 GIN @A1:X1,Y1
1450 MOVE @A1:13,Y1
1460 PRINT @A1:"DATA TAPE # ";T1
1470 PRINT @A1:C$;
1480 GIN @A1:X1,Y1
1490 MOVE @A1:13,Y1
1500 PRINT @A1:"FILE # ";Y
1510 AXIS @A1:1,0.1
```

Figure F-6. Continued.

```
1520 FOR I=6 TO 1494
1530    P5=0
1540    T5=0
1550    FOR J=I-5 TO I+5
1560       T5=T5+T(J)
1570       P5=P5+P(J)
1580    NEXT J
1590    IF T(I)=0 THEN 1630
1600    IF P(I)=0 THEN 1630
1610    MOVE @A1:I*0.01+0.005,T5/P5
1620    DRAW @A1:I*0.01+0.005,T5/P5
1630 NEXT I
1640 GO TO 670
1650 END
```

Figure F-6. Continued.

```
16 GO TO 4000
20 GO TO 5000
40 FIND 14
41 OLD
100 REM: FILE 15 STATISTICS AND PROBABILITY WITH PLOTTER OPTION
110 SET KEY
4000 REM:----------------------------------------------------STATISTICS
4010 PAGE
4020 PRINT "PROCESSING DATA GGGG"
4030 V=0
4040 A=SUM(T)
4050 B=SUM(P)
4060 M=A/B
4070 FOR I=M3*100 TO M4*100
4080     IF I=>1 THEN 4100
4090     I=1
4100     IF T(I)=0 THEN 4120
4110     V=(T(I)/P(I)-M)^2+V
4120 NEXT I
4130 V=V/(B-1)
4140 S=SQR(V)
4150 C=S/M
4160 PAGE
4170 PRINT "DATA TAPE # ";T1
4180 PRINT "FILE # ";Y
4190 PRINT "JJAREA SCANNED: ";M3;" TO ";M4;" INCHES"
4200 PRINT "MEAN THICKNESS: ";M
4210 PRINT "STANDARD DEVIATION: ";S
4220 PRINT "COEFFICIENT OF VARIATION: ";C
4230 PRINT "NUMBER OF READINGS: ";B
4240 PRINT "FILTERED THICKNESS: ";M1;" TO ";M2;" INCHES "
4250 WAIT
5000 REM:------------------------------------- PROBABILITY DISTRIBUTION
5010 PAGE
5020 PRINT "PROCESSING DATA GGGG"
5030 FOR I=1 TO 1500
5040     IF P(I)=0 THEN 5060
5050     T(I)=T(I)/P(I)
5060 NEXT I
5070 DELETE P
5080 DIM H(M2*1000)
5090 H=0
5100 FOR I=M3*100 TO M4*100
5110     IF I=>1 THEN 5130
5120     I=1
5130     IF T(I)=0 THEN 5160
5140     J=INT(T(I)*1000)
5150     H(J)=H(J)+1
5160 NEXT I
5170 A=0
5180 FOR I=1 TO M2*1000
5190     A=A MAX H(I)
5200 NEXT I
5210 PAGE
5220 PRINT "DO YOU WANT TO USE THE PLOTTER ? (Y OR N)";
5230 INPUT J$
5240 IF J$="Y" THEN 5270
5250 A1=32
5260 GO TO 5290
5270 PRINT "INPUT THE ADDRESS OF THE PLOTTER. ";
```

Figure F-6. Continued

```
5280 INPUT A1
5290 PAGE
5300 HOME @A1:
5310 WINDOW Ø,1,Ø,A
5320 VIEWPORT 1Ø,12Ø,1Ø,9Ø
5330 PRINT @A1:"TEST SPECIMEN -";
5340 GIN @A1:X1,Y1
5350 MOVE @A1:Ø.87,Y1
5360 PRINT @A1:"DATA TAPE # ";T1
5370 PRINT @A1:C$;
5380 GIN @A1:X1,Y1
5390 MOVE @A1:Ø.87,Y1
5400 PRINT @A1:"FILE # ";Y
5410 AXIS @A1:Ø.1,A/A+1
5420 MOVE @A1:Ø,Ø
5430 FOR I=1 TO M2*1ØØØ
5440     DRAW @A1:I*1.ØE-3,H(I)
5450     DRAW @A1:I*1.ØE-3+1.ØE-3,H(I)
5460 NEXT I
5470 MOVE @A1:Ø,Ø
5480 FOR I=Ø TO A STEP 2
5490     MOVE @A1:Ø,I
5500     PRINT @A1:"HH";I
5510 NEXT I
5520 MOVE @A1:Ø,Ø
5530 FOR I=Ø TO 1 STEP Ø.1
5540     MOVE @A1:I,Ø
5550     PRINT @A1:"HJ";I
5560 NEXT I
5570 HOME @A1:
5580 MOVE @A1:Ø,A/2+A/4
5590 V$=" R E A D I N G S"
5600 FOR I=1 TO LEN(V$)
5610     X$=SEG(V$,I,1)
5620     PRINT @A1:X$
5630 NEXT I
5640 MOVE @A1:Ø.35,Ø
5650 PRINT @A1:"JJJT H I C K N E S S";
5660 END
```

Figure F-6. Continued.

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DOE Div Ocean Energy Sys Cons/Solar Energy Wash DC
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NARF Code 100, Cherry Point, NC; Code 640, Pensacola FL; Equipment Engineering Division (Code 61000), Pensacola, FL
NAS CO, Guantanamo Bay Cuba; Code 114, Alameda CA; Code 183 (Fac. Plan BR MGR); Code 18700, Brunswick ME; Code 18U (ENS P.J. Hickey), Corpus Christi TX; Code 8E, Patuxent Riv., MD; Dir of Engrng, PWD, Corpus Christi, TX; Dir. Maint. Control Div., Key West FL; Dir. Util. Div., Bermuda; PW (J. Maguire), Corpus Christi TX; PWD - Engr Div, Gtmo, Cuba; PWD - Engr Div, Oak Harbor, WA; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Code 1821H (Pfankuch) Miramar, SD CA; PWD, Maintenance Control Dir., Bermuda; PWO Belle Chasse, LA; PWO Key West FL; PWO Lakehurst, NJ;

AD-A133 701 PULSE ECHO ULTRASONIC TECHNIQUES FOR UNDERWATER INSPECTION OF STEEL WATERFRONT STRUCTURES(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA 2/2

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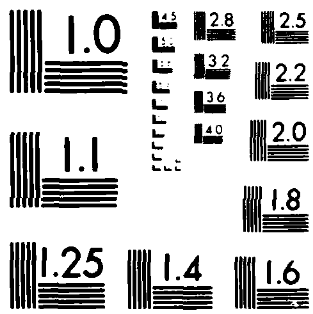

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

PWO, Dallas TX; PWO, Glenview IL; PWO., Moffett Field CA; SCE Norfolk, VA; SCE, Cubi Point, R.P; Security Offr, Alameda CA
NASDC-WDC T. Fry, Manassas VA
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NAVACT PWO, London UK
NAVACTDET PWO, Holy Lock UK
NAVAEROSPREGMEDCEN SCE, Pensacola FL
NAVAIRDEVCEN Code 813, Warminster PA
NAVAIRTESTCEN PATUXENT RIVER PWD (F. McGrath), Patuxent Riv.,MD
NAVAVIONICFAC PW Div Indianapolis, IN
NAVCHAPGRU Engineering Officer, Code 60 Williamsburg, VA
NAVCOASTSYSCEN Code 423 Panama City, FL; Code 715 (J Quirk) Panama City, FL; Code 715 (J. Mittleman) Panama City, FL; Code 719, Panama City, FL; Library Panama City, FL; PWO Panama City, FL
NAVCOMMAREAMSTRSTA PWO, Norfolk VA; SCE Unit 1 Naples Italy; SCE, Wahiawa HI
NAVCOMMSTA Code 401 Nea Makri, Greece; PWD - Maint Control Div, Diego Garcia Is.; PWO, Exmouth, Australia
NAVCONSTRACEN Curriculum Instr. Stds Offr, Gulfport MS
NAVEDTRAPRODEVCEN Technical Library, Pensacola, FL
NAVEDUTRACEN Engr Dept (Code 42) Newport, RI
NAVELEXSYSCOM Code PME 124-61, Washington, DC; PME 124-612, Wash DC
NAVEODTECHCEN Code 605, Indian Head MD
NAVFAC PWO, Centerville Bch, Ferndale CA
NAVFACENGCOM Alexandria, VA; Code 03 Alexandria, VA; Code 03T (Essoglou) Alexandria, VA; Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0453 (D. Potter) Alexandria, VA; Code 0453C, Alexandria, VA; Code 0454B Alexandria, Va; Code 04A1 Alexandria, VA; Code 09M54, Tech Lib, Alexandria, VA; Code 100 Alexandria, VA; Code 1113, Alexandria, VA
NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 405 Wash, DC; Code FPO-1C Washington DC; Code FPO-1E, Wash, DC; Contracts, ROICC, Annapolis MD; FPO-1 Washington, DC; FPO-1EA5 Washington DC; FPO-1P 1P3 Washington, DC; Library, Washington, D.C.
NAVFACENGCOM - LANT DIV. Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA; RDT&ELO 102A, Norfolk, VA
NAVFACENGCOM - NORTH DIV. (Boretsky) Philadelphia, PA; CO; Code 04 Philadelphia, PA; Code 09P Philadelphia PA; Code 1028, RDT&ELO, Philadelphia PA; Code 111 Philadelphia, PA; Code 405 Philadelphia, PA; Library, Philadelphia, PA; ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. (Kyi) Code 101, Pearl Harbor, HI; CODE 09P PEARL HARBOR HI; Code 2011 Pearl Harbor, HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI; Library, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 90, RDT&ELO, Charleston SC; Library, Charleston, SC
NAVFACENGCOM - WEST DIV. 102; Code 04B San Bruno, CA; Library, San Bruno, CA; O9P 20 San Bruno, CA; RDT&ELO Code 2011 San Bruno, CA
NAVFACENGCOM CONTRACTS AROICC, NAVSTA Brooklyn, NY; Colts Neck, NJ; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC-ROICC, NAS Oceana, Virginia Beach, VA; OICC/ROICC, Balboa Panama Canal; OICC/ROICC, Norfolk, VA; ROICC Code 495 Portsmouth VA; ROICC Key West FL; ROICC, Diego Garcia Island; ROICC, Keflavik, Iceland; ROICC, NAS, Corpus Christi, TX; ROICC, Pacific, San Bruno CA; ROICC, Point Mugu, CA; ROICC, Yap; ROICC-OICC-SPA, Norfolk, VA
NAVMAG PWD - Engr Div, Guam; SCE, Subic Bay, R.P.
NAVOCEANO Code 3432 (J. DePalma), Bay St. Louis MS; Library Bay St. Louis, MS
NAVOCEANSYSCEN Code 09 (Talkington), San Diego, CA; Code 4473 Bayside Library, San Diego, CA; Code 4473B (Tech Lib) San Diego, CA; Code 5204 (J. Stachiw), San Diego, CA; Code 5214 (H. Wheeler), San Diego CA; Code 5221 (R.Jones) San Diego Ca; Code 5322 (Bachman) San Diego, CA; Hawaii Lab (R Yumori) Kailua, HI; Hi Lab Tech Lib Kailua HI
NAVPETOFF Code 30, Alexandria VA
NAVPGSCOL C. Morers Monterey CA; E. Thornton, Monterey CA
NAVPHIBASE CO, ACB 2 Norfolk, VA; Code S3T, Norfolk VA; Harbor Clearance Unit Two, Little Creek, VA; SCE Coronado, SD,CA
NAVREGMEDCEN PWD - Engr Div, Camp Lejeune, NC; PWO, Camp Lejeune, NC; SCE; SCE, Camp Pendleton CA; SCE, Guam; SCE, Newport, RI
NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA
NAVSCSOL PWO, Athens GA
NAVSEASYSCOM Code OOC-D, Washington, DC; Code PMS 395 A 3, Washington, DC; Code PMS 395 A2, Washington, DC; Code SEA OOC Washington, DC; PMS-395 A1, Washington, DC; PMS395-A3, Washington, DC; SEA05E1, Washington, D.C
NAVSECGRUACT PWO, Adak AK
NAVSHIPREPFAC Library, Guam; SCE Subic Bay

NAVSHIPYD Bremerton, WA (Carr Inlet Acoustic Range), Code 134, Pearl Harbor, HI; Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA, Code 380, Portsmouth, VA, Code 400, Puget Sound; Code 410, Mare Is., Vallejo CA, Code 440 Portsmouth NH, Code 440, Norfolk, Code 440, Puget Sound, Bremerton WA; L.D. Vivian, Library, Portsmouth NH, PWD (Code 420) Dir Portsmouth, VA; PWD (Code 450-HD) Portsmouth, VA, PWD (Code 457-HD) Shop 07, Portsmouth, VA, PWD (Code 460) Portsmouth, VA; PWO, Bremerton, WA, PWO, Mare Is., PWO, Puget Sound, SCE, Pearl Harbor HI, Tech Library, Vallejo, CA

NAVSTA CO Roosevelt Roads P.R. Puerto Rico; Dir Engr Div, PWD, Mayport FL, Engr. Dir., Rota Spain, Long Beach, CA; Maint. Cont. Div., Guantanamo Bay Cuba, PWD (LTJG P.M. Motolenich), Puerto Rico, PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is., PWO, Guantanamo Bay Cuba, PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Guam, SCE, Pearl Harbor HI, SCE, San Diego CA, SCE, Subic Bay, R.P.

NAVSUBASE SCE, Pearl Harbor HI

NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD

NAVTECHTRACEN SCE, Pensacola FL

NAVWPNCEN Code 2636 China Lake; Code 3803 China Lake, CA

NAVWPNSTA (Clebak) Colts Neck, NJ; Code 092, Colts Neck NJ; Code 092, Concord CA, Maint. Control Dir., Yorktown VA

NAVWPNSTA PW Office Yorktown, VA

NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA, PWO, Charleston, SC; PWO, Seal Beach CA

NAVWPNSUPPCEN Code 09 Crane IN

NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 156, Port Hueneme, CA, PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI

NCR 20, Commander

NMCB FIVE, Operations Dept; Forty, CO; THREE, Operations Off.

NOAA (Dr. T. Mc Guinness) Rockville, MD; Library Rockville, MD

NORDA Code 410 Bay St. Louis, MS; Code 440 (Ocean Rsch Off) Bay St. Louis MS; Code 500, (Ocean Prog Off-Ferer) Bay St. Louis, MS

NRL Code 5800 Washington, DC; Code 5843 (F. Rosenthal) Washington, DC; Code 8441 (R.A. Skop), Washington DC

NROTC J.W. Stephenson, UC, Berkeley, CA

NSC Code 54.1 Norfolk, VA

NSD SCE, Subic Bay, R.P.

NUCLEAR REGULATORY COMMISSION *T.C. Johnson, Washington, DC*

NUSC Code 131 New London, CT; Code 332, B-80 (J. Wilcox) New London, CT; Code EA123 (R.S. Munn), New London CT; Code TA131 (G. De la Cruz), New London CT

ONR Central Regional Office, Boston, MA; Code 481, Bay St. Louis, MS; Code 485 (Silva) Arlington, VA; Code 700F Arlington VA

PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI

PHIBCB 1 P&E, San Diego, CA

PMTC Code 3144, (E. Good) Point Mugu, CA; EOD Mobile Unit, Point Mugu, CA

PWC CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; CO, Pearl Harbor HI; Code 10, Great Lakes, IL; Code 105 Oakland, CA; Code 110, Oakland, CA; Code 120, Oakland CA; Code 128, Guam; Code 154 (Library), Great Lakes, IL; Code 200, Great Lakes IL; Code 200, Guam; Code 400, Great Lakes, IL; Code 400, Oakland, CA; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 500 Norfolk, VA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 700, San Diego, CA; Library, Code 120C, San Diego, CA; Library, Pensacola, FL; Library, Guam; Library, Norfolk, VA; Library, Oakland, CA; Library, Pearl Harbor, HI; Library, Subic Bay, R.P.; Library, Yokosuka JA; Utilities Officer, Guam

SUPANX PWO, Williamsburg VA

TVA Solar Group, Arnold, Knoxville, TN

UCT ONE OIC, Norfolk, VA

UCT TWO OIC, Port Hueneme CA

US DEPT OF INTERIOR Bur of Land Mgmnt Code 583, Washington DC

US GEOLOGICAL SURVEY Off. Marine Geology, Piteleki, Reston VA

USCG (G-MP-3/USP/82) Washington Dc; (Smith), Washington, DC; G-EOE-4 (T Dowd), Washington, DC

USCG R&D CENTER CO Groton, CT; D. Motherway, Groton CT

USDA Forest Products Lab. (R. DeGroot), Madison WI; Forest Service Reg 3 (R. Brown) Albuquerque, NM; Forest Service, San Dimas, CA

USNA Ch. Mech. Engr. Dept Annapolis MD; ENGRNG Div, PWD, Annapolis MD; PWO Annapolis MD; USNA/SYS ENG DEPT ANNAPOLIS MD

USS FULTON WPNS Rep. Offr (W-3) New York, NY

WATER & POWER RESOURCES SERVICE (Smoak) Denver, CO

NUSC Library, Newport, RI

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